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An Evaluation of Freshwater Mussels in the Lower Ohio River in Relation to the Olmstead Locks and Dam Project: 1995, 1996, and 1997 Studies

by Barry S. Payne, Andrew C. Miller

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Prepared for U.S. Army Engineer District, Louisville

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U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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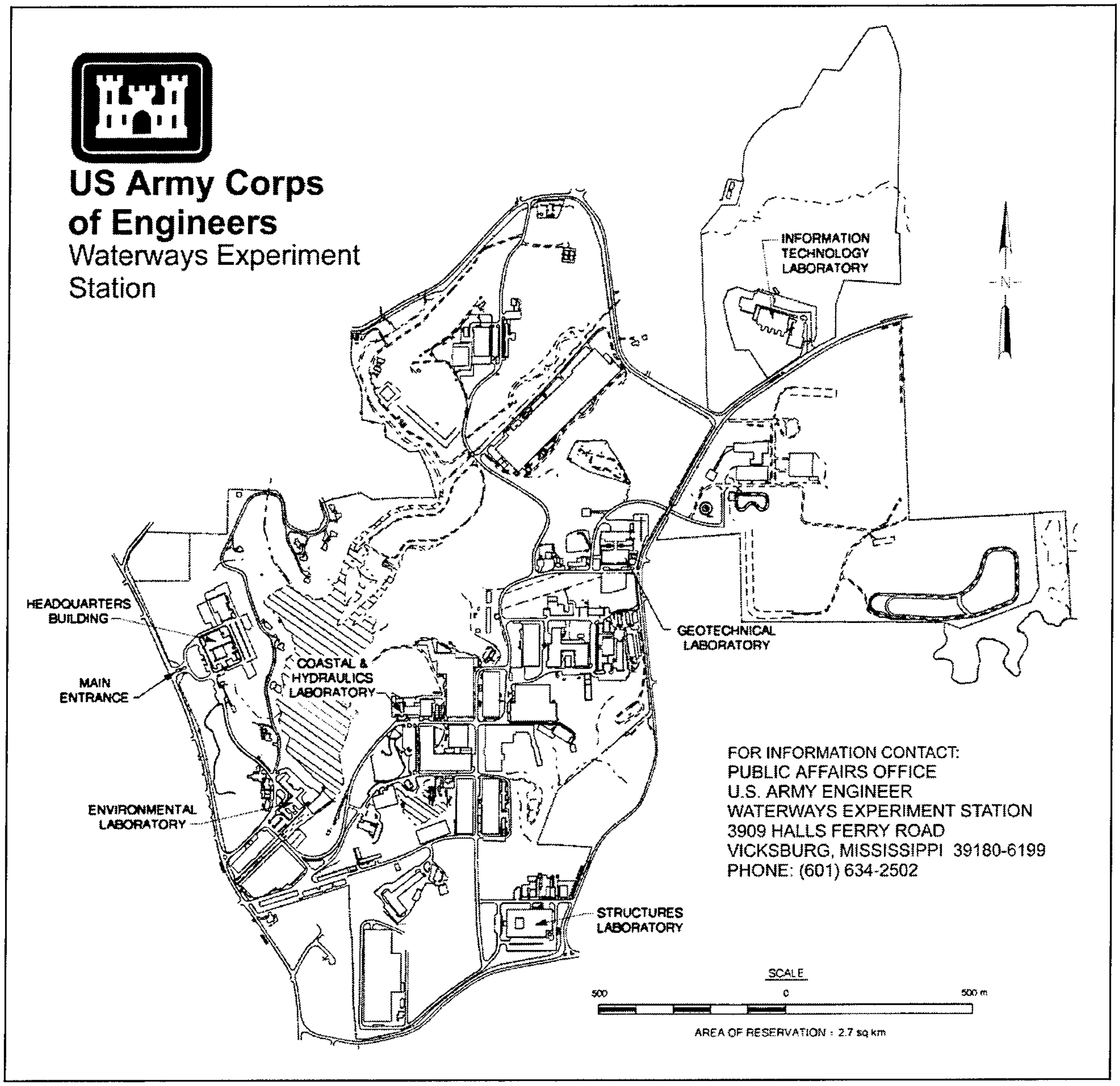

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Preface

The study herein was conducted by the U.S. Army Engineer Waterways Experiment Station (WES) in 1995, 1996, and 1997 for the U.S. Army Engineer District, Louisville, Louisville, KY. The purpose was to analyze spatial distribution, density, recruitment, and community composition of mussels in prominent beds in the lower Ohio River in relation to construction and operation of the Olmsted Locks and Dam Project.

Divers for this study were from the Tennessee Valley Authority and included Messrs. Larry Neill, Robert Warden, Robert James, Dennis Baxter, and Johnny Buchanan. Assistance in the field was provided by Mr. Thomas Ussery, University of Texas at Arlington, and Dr. Larry Shaffer, University of Mississippi. Dr. Andrew C. Miller was the diving inspector for this work. Assistance in the laboratory was provided by Ms. Stacey Poor, Millsaps College, and Ms. Ginny Adams, University of Arkansas.

During the conduct of this study, Drs. John Keeley and John Harrison were Director, EL; Dr. Conrad J. Kirby was Chief, Ecological Resources Division (ERD), EL; and Drs. Alfred F. Cofrancesco and Edwin A. Theriot were Chief, Aquatic Ecology Branch (AEB), ERD. Authors of this report were Drs. Barry S. Payne and Andrew C. Miller, AEB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

This report should be cited as follows:

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles (U.S. nautical)	1.852	kilometers

1 Introduction

Background

The U.S. Army Engineer District, Louisville, is replacing Locks and Dams 52 and 53 in the lower Ohio River with a new structure located slightly downstream of Lock and Dam 53 (U.S. Army Corps of Engineers 1991) near Olmsted, IL. The structure being built will consist of two 110- by 1,200-ft[1] locks, a 2,200-ft-wide navigable pass controlled by remotely operated hydraulic wickets, and a short section of fixed weir connecting the project to the Kentucky shore. The new locks will be on the right descending bank (RDB) on the Illinois side of the river. During periods of normal and low flow, navigation will pass through the locks. During high flow, vessels will use the navigable pass near the center of the channel. The new project, now being constructed, is at River Mile (RM) 964.4. Existing Lock and Dam 53 is at RM 962.8, and existing Lock and Dam 52 is at RM 938.9.

Once completed, the Olmsted project will increase water levels by a maximum of 10 ft in the pool above the dam for approximately 42 percent of the year. This increased stage will occur only during normal and low flow. During high-water periods (58 percent of the year), dam sections will be lowered to a horizontal position on the river bottom. Upriver stage will be similar to preproject conditions when these dam sections are down. In addition to upstream changes, the hydraulic regimen immediately downstream of the new structure will be altered, as will existing navigation traffic patterns. Commercial vessels will have to pass close to the RDB when entering or exiting the lock. During high water, commercial vessels will operate in the thalweg at RM 964.4, as they have always done.

Potential changes in hydraulics and traffic patterns immediately downriver of the new project are of special interest with respect to a dense and diverse bed of mussels that begins at approximately RM 966 and extends several miles downstream (Payne, Miller, and Shafer 1994; Payne and

1 A table of factors for converting non-SI units of measurement to SI units can be found on page xi.

Miller 1997). This bed includes the endangered species *Plethobasus cooperianus* (U.S. Fish and Wildlife Service 1991). In addition, the bed and other species have economic, ecological, and cultural value deserving protection. Results of previous surveys and studies of this prominent mussel bed are included in publications by Williams (1969), Williams and Schuster (1982), Taylor (1989), Neff, Pearson, and Holdren (1981), Miller, Payne, and Siemsen (1986), Miller and Payne (1988), Miller and Payne (1991), Payne and Miller (1989), Payne, Miller, and Shafer (1994), and Payne and Miller (1997).

Freshwater mussels can be affected by changes in water level, sedimentation, sediment erosion, sediment resuspension caused by dredging and disposal of dredged material, and movement of navigation vessels. Their essentially infaunal and sedentary lifestyle and reliance on suspended organic particles for nutrition make them potentially susceptible to altered hydraulic and physical conditions. Biological consequences of such disturbances can be measured on animals held in the laboratory (Holland 1986; Aldridge, Payne, and Miller 1987; Killgore, Miller, and Conley 1987; Payne and Miller 1987; Payne, Miller, and Aldridge 1987; Payne, Killgore, and Miller 1990). However, caution must be taken when laboratory studies are the basis of predictions about natural populations (Payne and Miller 1987). Physiological responses that can be elicited in stylized laboratory studies often cannot be observed in more complex natural situations.

Although laboratory studies are useful for identifying potential adverse effects and their probable causes, field studies are needed to verify that physical disturbances result in measurable effects on naturally occurring mussels, populations, and communities. Planners and biologists evaluating ecological consequences of such physical disturbances should rely on field evaluations of natural populations. Field studies can be designed to evaluate physical effects of water resource development on individual growth and condition, population density, recruitment, and mortality, and community composition, including the number of species, their relative abundance, and diversity. Such parameters provide the most useful measures of health and survival of a diverse mussel community.

Purpose and Scope

The objective of the present study is to evaluate the spatial distribution of mussels in the bed downstream of the Olmsted project as well as selected locations in the upriver pool. Additional objectives are to characterize recruitment patterns, community composition, and density of nonindigenous species, including the Asian clam, *Corbicula fluminea*, and the zebra mussel, *Dreissena polymorpha*. These quantitative data can be used to assess environmental effects of alterations of hydraulic regimen, commercial navigation traffic patterns, and benthic scour and deposition associated with construction and operation of the Olmsted project. It is anticipated that studies will continue until the project has operated for at least several years.

2 1995 Studies

Sites and Methods

Sampling was conducted in both July and October of 1995. Samples were collected downriver of the Olmsted Locks and Dam Project between RM 967 and 969 from 22 to 25 July. Sampling in October was at three locations, near Olmsted (RM 967.6 and 968.3), Post Creek (RM 956.5 and 957.6), and Four Mile Creek (RM 940.5).

In July 1995, emphasis was on verifying and adding detail to a previous map (see Payne and Miller 1997) of the Olmsted mussel bed. Thus, the dive boat was repositioned many times over the bed, and at each boat position, divers worked their way along 100-ft lines. One diver moved in the nearshore direction, and a second diver moved in the farshore direction. Divers described substratum and unionid, *Corbicula*, and *Dreissena* density to a data recorder in the boat. Approximately 100 ft from the boat, each diver stopped and collected two semiquantitative samples, searching by touch for all unionids within a 0.25-m^2 quadrat. Adjacent to these semiquantitative sample sites, two quantitative samples of *Dreissena* were collected using 0.0625-m^2 quadrats.

In addition, 10 replicate quantitative samples of substratum with mussels were collected at four sites within the mussel bed. Quantitative samples consisted of divers excavating all substratum and mussels from within 0.25-m^2 quadrats; this material was placed in buckets, winched to the surface, and taken to shore for processing using nest sieve screens.

Latitudinal and longitudinal coordinates of dive boat anchorage positions for these semiquantitative and quantitative samples in July 1995 are summarized in Table 1. Also indicated in Table 1 is information on depth and bottom elevation at each location.

Sampling from 21-22 October at Olmsted, Post Creek, and Four Mile Creek involved qualitative and quantitative sampling for native mussels, plus special additional quantitative sampling for low-density populations of zebra mussels. Qualitative samples consisted of divers collecting all unionids encountered by feel. This sampling was incremental. The first

Table 1
Locations and Elevations of July 1995 Samples from a Mussel Bed in the Lower Ohio River near Olmstead, IL

Latitude (degrees North)	Longitude (degrees West)	Samples	Elevation (feet above mean sea level)[1]
3709.394	8905.583	4-1 near (n = 2) 4-2 far (n = 2) Quantitative IV (n = 10)	279 266 268
3709.260	8905.624	5-1 near (n = 2) 5-2 far (n = 2) Quantitative III (n = 10)	273 266 270
3709.056	8905.690	6-1 near (n = 2) 6-2 far (n = 2) Quantitative II (n = 10)	274 277 274
3709.036	8905.650	6-3 near (n = 2) 6-4 far (n = 2)	270 268
3708.801	8905.734	7-1 near (n = 2) 7-2 far (n = 2) Quantitative I (n = 10)	274 271 274
3708.684	8905.880	8-1 near (n = 2) 8-2 far (n = 2)	280 276
3708.946	8905.730	7-2 near (n = 2) 7-2 far (n = 2)	275 275
3708.642	8905.800	8-3 near (n = 2) 8-4 far (n = 2)	276 272
3708.662	8905.758	8-5 near (n = 2) 8-6 far (n = 2)	271 269
3708.596	8905.859	9-1 near (n = 2) 9-2 far (n = 2)	274 273
3708.429	8906.003	10-1 near (n = 2) 10-2 far (n = 2)	281 280
3708.391	8905.932	10-3 near (n = 2) 10-4 far (n = 2)	280 272
3708.311	8905.865	10-5 near (n = 2) 10-6 far (n = 2)	270 269
3708.134	8906.138	11-1 near (n = 2) 11-2 far (n = 2)	280 278
3708.128	8906.056	11-3 near (n = 2) 11-4 far (n = 2)	275 271
3708.129	8905.966	11-5 near (n = 2) 11-6 far (n = 2)	269 268
3707.946	8906.221	14-1 near (n = 2) 14-2 far (n = 2)	282 280
3707.929	8906.164	14-3 near (n = 2) 14-4 far (n = 2)	276 271
3707.914	8906.069	14-5 near (n = 2) 14-6 far (n = 2)	267 267

[1] To convert feet to meters, multiply by 0.3048.

three samples consisted of five mussels each, followed by nine samples of 20 mussels each. Quantitative sampling consisted of 10 replicate 0.25-m^2 substratum with mussel samples at each of three sites at Olmsted (RMs 967.6, 968.3 near Buoy No. 3, and 967.5), two sites at Post Creek (RMs 957.6 and 956.5), and one site at Four Mile Creek (RM 940.5). In addition, five replicate 0.25-m^2 samples were taken just for *Dreissena* at single sites at Olmsted (RM 957.5), Post Creek (RM 956.5), and Four Mile Creek (RM 940.5). These samples involved placing all surficial hard substratum (cobble, gravel, and unionids) from each quadrat into buckets that were winched to the surface, taken to shore, and then carefully inspected for attached zebra mussels. The low density of zebra mussels encountered in October 1995 required limited sampling to estimate the density of just that species.

Results

Mussel density and spatial distribution in the Olmsted bed

Thirty-eight semiquantitative sampling sites ranged in location from approximately RM 967.1 to 968.7. Sites spanned an elevation range of approximately 282 ft in the nearshore direction to approximately 263 ft in the farshore direction (Table 1).

Semiquantitative sampling of native unionids indicated that the nearshore and farshore limits of the mussel bed approximately correspond to the 280- and 265-ft elevation contours (Figure 1). Unionid density in semiquantitative samples ranged from 0 to 208 individuals per square meter. Some of these sites without mussels were intentionally selected to represent conditions just outside the nearshore and farshore limits of the bed. Elevation at sites of high density (>50 individuals per square meter) ranged from 267 to 277. Sites at 266-ft elevation or lower supported no unionids. Sites higher than 279-ft elevation typically supported low densities. One site at elevation 280 yielded a moderately high density of 40 mussels per square meter. Mussel density was not uniformly high within the 267 to 279 elevation range; approximately half of the sites sampled within this elevation range yielded low or moderate densities of unionids.

Elevation contours reasonably delineated the nearshore and farshore limits of the mussel bed. However, within these broad limits, substantial variation in density occurred. As an example, at one of the sampling sites, a diver semiquantitatively sampling two replicate (adjacent) 0.25-m^2 quadrats obtained 23 unionids in his first sample (92 individuals per square meter) and no unionids in his second sample. Within the mussel bed, unionid density shows some association with substratum (Figure 2). Sites of high density (>50 individuals per square meter) tend to occur in gravelly

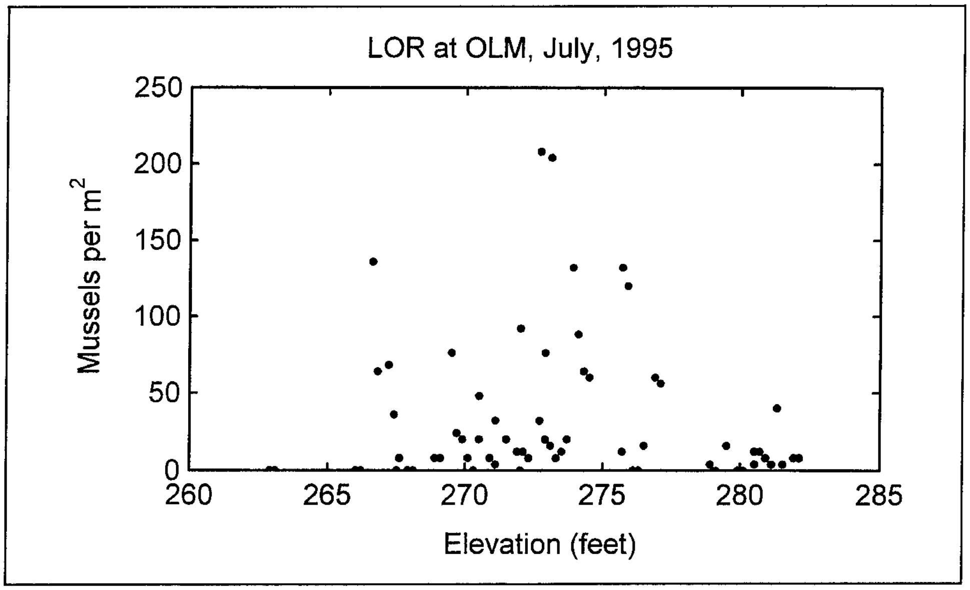


Figure 1. Native mussel density in relation to elevation, Lower Ohio River, July 1995

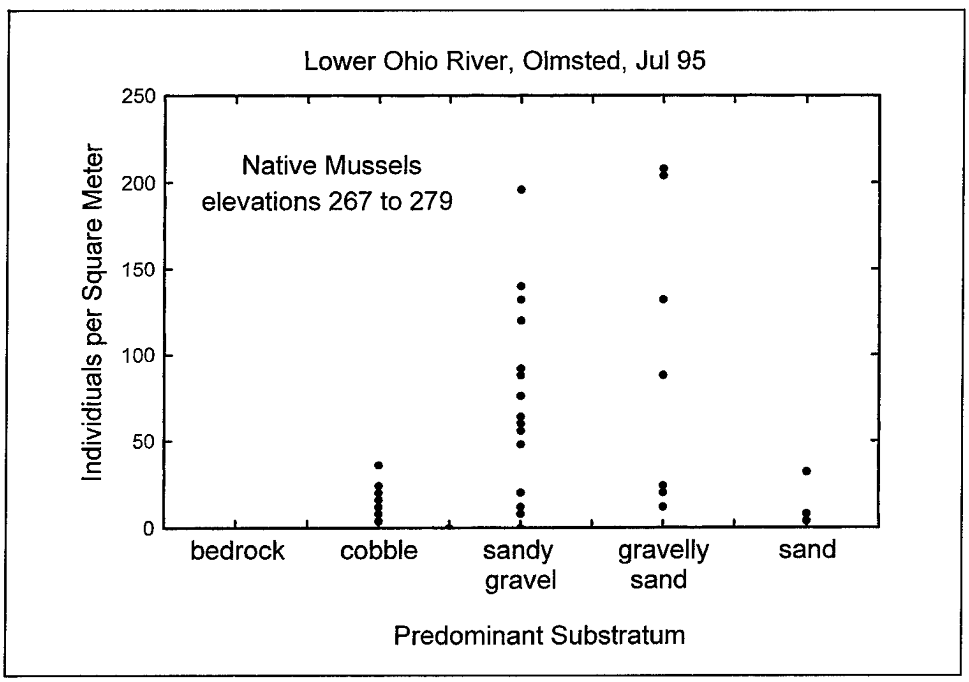


Figure 2. Native mussel density in relation to predominant substratum type, Lower Ohio River, July 1995

sand or sandy gravel, while sites that are predominantly cobble or are entirely sand tend to support only low densities of mussels. Typically, sites farshore of the mussel bed were characterized by erosional sand. Sites nearshore of the mussel bed were comprised of virtually the same substratum as sites between the 279- and 267-ft contours.

Unionid density at the four sites quantitatively sampled in July 1995 ranged from an average of 11.6 individuals per square meter at Site IV to 108.0 individuals per square meter at Site II (Table 2). It is noteworthy that Site IV was very close to the farshore limit of the mussel bed, possibly accounting for the relatively low density observed at that site. In addition to providing accurate density data, quantitative samples are important in that they yield accurate information on recent recruitment of mussels. Evidence of recent recruitment, indicated by the percent individuals less than 30 mm long, was very strong at Site II (69 percent) and Site III (53 percent), moderate at Site IV (31 percent), and lowest, but still considerable, at Site I (14 percent) (Table 3). As will be discussed later, much of this intersite variation in percent individuals less than 30 mm long reflected intersite differences in the length of individuals of a heavily dominant 1990 cohort of the dominant mussel, *Fusconaia ebena*, which had attained greater size at Sites I and IV than II and III.

Table 2
Mean Density and Standard Error of the Mean for Total Unionids and *Corbicula fluminea*, Lower Ohio River, July 1995

Subsite	N	Unionidae		*C. fluminea*	
		Mean	SE	Mean	SE
1	10	106.4	34.3	0.4	0.4
2	10	108.0	9.0	57.2	5.3
3	10	60.0	7.8	3.2	1.7
4	10	11.6	3.3	2.8	0.9

The three sites quantitatively sampled in October 1995 all supported high-density unionid communities (92 to 156 individuals per square meter). Evidence of recent recruitment, defined as mussels less than 30 mm long, was greater at Sites 1 and 2 (41 to 42 percent of all unionids collected were less 30 mm) than at Site 3 (8.5 percent of mussels were less than 30 mm). However, as in July, these intersite differences primarily reflected differences in the length of the very abundant 1990 cohort of *Fusconaia ebena*. Indeed, the 1990 cohort of *F. ebena* dominated the entire native mussel community at Olmsted. These intersite differences in growth of the 1990 cohort of *F. ebena* will be analyzed in more detail later.

Table 3
Percent Abundance of Unionidae Collected in 10 0.25-m² Quadrat Samples Collected at the Lower Ohio River near Olmsted, IL, July 1995

Species	Subsite 1	Subsite 2	Subsite 3	Subsite 4	Total
F. ebena	93.61	88.15	84.67	62.07	88.39
Q. pustulosa	0.75	4.44	2.00	6.90	2.66
E. lineolata	0.38	2.22	2.67	0.00	1.54
E. crassidens	0.38	0.74	4.00	3.45	1.40
O. reflexa	2.63	0.74	0.00	3.45	1.40
Q. quadrula	0.38	1.11	2.00	10.34	1.40
A. p. plicata	0.75	0.37	1.33	6.90	0.98
M. nervosa	0.00	0.00	1.33	3.45	0.42
L. teres	0.00	0.37	0.67	3.45	0.42
L. fragilis	0.75	0.00	0.00	0.00	0.28
O. olivaria	0.00	0.37	0.67	0.00	0.28
T. truncata	0.00	0.74	0.00	0.00	0.28
F. alatus	0.38	0.00	0.67	0.00	0.28
Q. nodulata	0.00	0.37	0.00	0.00	0.14
L. recta	0.00	0.37	0.00	0.00	0.14
Total species	9	12	10	8	15
Total individuals	266	270	150	29	715
% Species <30 mm	22.22	33.33	10	25	26.67
% Individuals <30 mm	13.54	69.26	53.33	31.03	46.64
Menhinick's index	0.55	0.73	0.82	1.48	0.56
Species diversity	0.35	0.60	0.74	1.36	0.62
Evenness	0.33	0.35	0.36	0.54	0.32

Native mussel community composition

Olmsted. The native mussel community reflected by semiquantitative sampling in July was heavily dominated by *Fusconaia ebena* (Table 4). This species accounted for 88.9 percent of all unionids obtained. A total of 17 species were included among 675 individuals collected by search and feel within 0.25-m^2 quadrats. Semiquantitative sampling yielded a high number of relatively small, recently recruited mussels; 34.7 percent of all individuals obtained were less than 30 mm long. Because of the heavy dominance of *F. ebena*, diversity was low, measuring 0.61 (Shannon-Weaver index) and 0.65 (Menhinick's index). Evenness, with a maximum possible value of 1.0, measured only 0.32.

Table 4
Summary Statistics for Mussel Data Collected by Search and Feel Methods Using a 0.25-m² Quadrat, Lower Ohio River, July 1995

Species	Abundance		Occurrence	
	Total	**%**	**Total**	**%**
F. ebena	600	88.89	59	92.19
Q. p. pustulosa	15	2.22	11	17.19
E. lineolata	12	1.78	9	14.06
O. reflexa	10	1.48	9	14.06
Q. quadrula	10	1.48	10	15.63
Q. metanevra	9	1.33	9	14.06
E. crassidens	5	0.74	5	7.81
O. olivaria	3	0.44	3	4.69
A. p. plicata	2	0.30	2	3.13
L. recta	2	0.30	2	3.13
P. cordatum	1	0.15	1	1.56
L. teres	1	0.15	1	1.56
P. alatus	1	0.15	1	1.56
L. fragilis	1	0.15	1	1.56
M. nervosa	1	0.15	1	1.56
T. donaciformis	1	0.15	1	1.56
T. truncata	1	0.15	1	1.56
Total individuals	675			
Total quadrats	64			
% Individuals <30 mm	34.70			
% Species <30 mm	29.41			
Menhinick's index	0.65			
Species diversity	0.61			
Evenness	0.32			

Community composition of native mussels was not much different based on quantitative than semiquantitative sampling. Averaged for all four sites quantitatively sampled in July 1995, *Fusconaia ebena* comprised 88.4 percent of the community (Table 3) and occurred in 93 percent of all quadrats sampled (Table 5). A total of 15 species were represented among 715 individuals collected by quantitative methods. Individuals less than 30 mm, representing recent recruitment, comprised 46.6 percent of the

Table 5
Percent Occurrence of Unionidae Collected in 10 0.25-m² Quadrat Samples Collected at the Lower Ohio River near Olmsted, IL, July 1995

Species	Subsite 1	Subsite 2	Subsite 3	Subsite 4	Total
F. ebena	100.0	100.0	100.0	70.0	92.5
Q. pustulosa	20.0	70.0	20.0	20.0	32.5
E. lineolata	10.0	20.0	60.0	10.0	25.0
E. crassidens	60.0	20.0	0.0	10.0	22.5
O. reflexa	10.0	30.0	20.0	30.0	22.5
Q. quadrula	10.0	30.0	30.0	0.0	17.5
A. p. plicata	20.0	10.0	20.0	20.0	17.5
M. nervosa	0.0	0.0	20.0	10.0	7.5
L. teres	0.0	10.0	10.0	10.0	7.5
L. fragilis	10.0	0.0	10.0	0.0	5.0
O. olivaria	0.0	10.0	10.0	0.0	5.0
T. truncata	0.0	20.0	0.0	0.0	5.0
P. alatus	20.0	0.0	0.0	0.0	5.0
Q. nodulata	0.0	10.0	0.0	0.0	2.5
L. recta	0.0	10.0	0.0	0.0	2.5
Total samples	10	10	10	10	40

community. Due to the extreme dominance of *F. ebena*, diversity was low (Shannon-Weaver index = 0.62; Menhinick's index = 0.56). Evenness equaled on 0.32.

Quantitative Sites 1-3 were heavily dominated by *F. ebena* and supported high densities of unionids (60 to 108 individuals per square meter). Site 4 was less heavily dominated by *F. ebena* and supported only 12 individuals per square meter.

Fifteen species were obtained in quantitative and semiquantitative samples at Olmsted in July 1995. These were *Fusconaia ebena*, *Quadrula pustulosa*, *Ellipsaria lineolata*, *Obliquaria reflexa*, *Quadrula quadrula*, *Q. metanevra*, *Elliptio crassidens*, *Obovaria olivaria*, *Amblema plicata*, *Ligumia recta*, *Lampsilis teres*, *Potamilus alatus*, *Leptodea fragilis*, *Megalonaias nervosa*, and *Truncilla truncata*. Two species, *Pleurobema cordatum* and *Truncilla donaciformis*, were obtained by semiquantitative but not quantitative methods. One species, *Q. nodulata*, was obtained in quantitative but not qualitative samples. Thus, a total of 18 species were represented among 1,390 individuals collected by quantitative and qualitative methods in July 1995.

Qualitative sampling for unionids was conducted at three sites at Olmsted in October 1995. Samples 1, 3, and 4 summarized in Table 6 represent qualitative sampling at Olmsted in October 1995. A total of 503 individuals and 16 species of native mussels were obtained from these three samples (Table 6). Dominance of *F. ebena* ranged from 70.9 to 94 percent.

Three sites were quantitatively sampled (n = 10 0.25-m^2 quadrats per site) in October 1995 (Table 7). *Fusconaia ebena* comprised 91.0 percent of the 870 mussels collected by quantitative methods and was present in every quadrat sampled (Table 7). Consequently, species diversity was low (0.51 Shannon Weaver and 0.54 Menhinick's index). Evenness of species relative abundance measured only 0.31. A total of 16 species were represented among 870 individuals collected in October.

Eight species were obtained in both qualitative and quantitative samples. These were *F. ebena*, *Q. pustulosa*, *Q. quadrula*, *E. lineolata*, *A. plicata*, *E. crassidens*, *O. reflexa*, *Q. metanevra*, and *O. olivaria*. In addition, eight species were obtained in qualitative but not quantitative samples. These included *P. alatus*, *Q. nodulata*, *Cyclonaias tuberculata*, *P. cordatum*, *L. recta*, *Lasmigona complanata,* and *Plethobasus cyphyus*. Six species were obtained in quantitative but not qualitative samples. These were *T. truncata*, *M. nervosa*, *L. fragilis*, *L. teres*, *Tritigonia verrucosa*, and *F. flava*. Thus, a total of 23 species were represented among 1,373 individuals collected by combined qualitative and quantitative methods in October 1995. Only one species among the 1,390 mussels collected in July, *Truncilla donaciformis*, was not also represented in October sampling results. Thus, all sampling in 1995 at Olmsted included 24 species among 2,763 individuals.

Post Creek. *Fusconaia ebena* was much lower in relative abundance near Post Creek than at Olmsted. Qualitative sampling yielded a total of 357 individuals from Samples 2 and 5 (summarized in Table 6) taken at Post Creek. Sixteen species were represented among these individuals. *Fusconaia ebena* comprised 26.0 percent of the community at one of the qualitative sites, ranking only slightly ahead of *Q. pustulosa* (21.5 percent) and *O. reflexa* (17.1 percent) as the dominant native mussel. At the second qualitative site, *Q. pustulosa* was dominant (22.6 percent), closely followed in relative abundance by *F. ebena* (17.1 percent) and *O. reflexa* (15.1 percent).

Quantitative sampling at two sites near Post Creek showed *F. ebena* to be substantially higher in relative abundance than did qualitative sampling (Table 8). At one quantitative site, *F. ebena* comprised 35.7 percent of the community, and at the other sites *F. ebena* accounted for 51.7 percent of all individuals collected (Table 9). The moderate dominance of *F. ebena* resulted in moderately high species diversity (1.82 Shannon Weaver and 0.98 Menhinick). Evenness of species relative abundance was moderately high,

Table 6
Summary Data for Unionids Collected Using Qualitative Methods at Six Locations in the Lower Ohio River, October 1995[1]

Species	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Total % Abund	% Freq of Occur
F. ebena	94.00	25.95	70.94	87.63	17.09	79.47	62.86	100.00
Q. pustulosa	1.00	21.52	5.13	0.54	22.61	3.16	8.95	100.00
E. lineolata	1.00	13.29	5.98	3.23	7.04	2.11	5.14	100.00
Q. quadrula	0.00	8.86	0.85	0.00	15.08	1.58	4.57	66.67
O. reflexa	1.00	17.09	1.71	1.61	4.52	2.63	4.57	100.00
Q. metanevra	2.00	2.53	7.69	1.61	4.52	1.05	2.95	100.00
O. olivaria	0.50	1.27	1.71	3.23	0.50	0.53	1.24	100.00
F. alatus	0.50	0.63	0.00	0.54	5.03	0.00	1.24	66.67
M. nervosa	0.00	0.63	0.00	0.00	4.52	1.05	1.14	50.00
Q. nodulata	0.00	0.63	0.85	0.00	2.01	1.58	0.86	66.67
C. tuberculata	0.00	2.53	0.00	0.54	1.51	0.00	0.76	50.00
T. truncata	0.00	0.63	0.00	0.00	2.01	0.53	0.57	50.00
A. p. plicata	0.00	2.53	1.71	0.00	11.56	6.32	3.90	66.67
P. cordatum	0.00	0.63	0.00	0.54	0.50	0.00	0.29	50.00
C. crassidens	0.00	0.63	0.00	0.54	0.50	0.00	0.29	50.00
T. verrucosa	0.00	0.63	0.00	0.00	1.01	0.00	0.29	33.33
L. recta	0.00	0.00	1.71	0.00	0.00	0.00	0.19	16.67
L. complanta	0.00	0.00	0.85	0.00	0.00	0.00	0.10	16.67
P. cyphyus	0.00	0.00	0.85	0.00	0.00	0.00	0.10	16.67
Total individuals	200	158	117	186	199	190	1,050	
Total species	7	16	12	10	16	11	19	

[1] Sample 1 - RM 967.6; Sample 2 - RM 957.6, Post Creek Area; Sample 3 - LOR Buoy No. 3; Sample 4 - Transect 8; Sample 5 - RM 956.5, Post Creek Area; and Sample 6 - RM 940.5.

equaling 0.59. A total of 218 individuals were collected by quantitative methods, with 14 species represented among those individuals. Evidence of community-wide recruitment was strong, with 57 percent of all species including at least one individual less than 30 mm long. Recent recruitment of *F. ebena* clearly was less than at Olmsted, with only 18 percent of all individual mussels collected, of which *F. ebena* was dominant.

Fourteen species were collected by both quantitative and qualitative methods. These species were *F. ebena*, *O. reflexa*, *Q. pustulosa*, *E. lineolata*, *Q. quadrula*, *A. plicata*, *C. tuberculata*, *T. truncata*, *Q. metanevra*,

Table 7
Percent Species Abundance at the Olmsted Mussel Bed, October 1995

Species	Site 1	Site 2	Site 3	Total
F. ebena	93.70	82.53	94.32	91.03
Q. p. pustulosa	3.54	4.37	0.78	2.53
Q. quadrula	1.18	3.06	0.26	1.26
E. lineolata	0.79	1.31	0.78	0.92
A. p. plicata	0.39	1.75	0.26	0.69
E. crassidens	0.00	1.31	0.78	0.69
O. reflexa	0.00	1.31	0.52	0.57
Q. metanevra	0.00	0.44	1.03	0.57
T. truncata	0.00	0.44	1.03	0.57
O. olivaria	0.00	0.87	0.26	0.34
M. nervosa	0.00	0.87	0.00	0.23
L. fragilis	0.00	0.87	0.00	0.23
L. teres	0.00	0.44	0.00	0.11
T. verrucosa	0.00	0.44	0.00	0.11
F. flava	0.39	0.00	0.00	0.11
Total individuals	254	229	387	870
Total species	6	15	10	16
% Individuals <30 mm	42.12	40.61	8.53	26.78
% Species <30 mm	33.33	42.85	30	46.67
Menhinick's index	0.38	0.99	0.51	0.54
Species diversity	0.31	0.87	0.34	0.51
Evenness	0.37	0.33	0.31	0.31

P. alatus, *M. nervosa*, *T. verrucosa*, *E. crassidens*, and *O. olivaria*. All species collected by quantitative methods were also collected by qualitative methods. Two species, *P. cordatum* and *Q. nodulata*, were obtained in qualitative but not quantitative samples. Thus, a total of 16 species were represented among 575 individuals collected by both methods.

Four Mile Creek. *Fusconaia ebena* was heavily dominant at Four Mile Creek in October 1995 (Sample 6 in Table 6). Similar to its heavy dominance in the lower Ohio River near Olmsted, *F. ebena* comprised

Table 8
Percent Frequency of Occurrence of Species at the Olmsted Mussel Bed, October 1995

Species	Site 1	Site 2	Site 3	Total
F. ebena	100.0	100.0	100.0	100.0
Q. p. pustulosa	40.0	70.0	30.0	46.7
Q. quadrula	30.0	50.0	10.0	30.0
E. lineolata	10.0	30.0	30.0	23.3
A. p. plicata	10.0	30.0	10.0	16.7
E. crassidens	0.0	30.0	20.0	16.7
O. reflexa	0.0	30.0	20.0	16.7
Q. metanevra	0.0	10.0	30.0	13.3
T. truncata	0.0	10.0	40.0	16.7
O. olivaria	0.0	20.0	10.0	10.0
M. nervosa	0.0	10.0	0.0	3.3
L. fragilis	0.0	20.0	0.0	6.7
L. teres	0.0	10.0	0.0	3.3
T. verrucosa	0.0	10.0	0.0	3.3
F. flava	10.0	0.0	0.0	3.3
Total quadrats	10	10	10	30

79 percent of all unionids collected in qualitative samples from the lower Ohio River at Four Mile Creek. A total of 11 species were represented among 190 mussels collected at Four Mile Creek. No species were collected at Four Mile Creek that were not also collected at either the Post Creek or Olmsted sites.

Size demography of native mussels. The size distribution of *F. ebena* obtained in semiquantitative samples in July at Olmsted is shown in Figure 3. Approximately 75 percent of the population thus sampled was ranged from 20 to 40 mm long. These 20- to 40-mm-long individuals represent 1990 recruits (Payne and Miller 1997). Most of the remaining 25 percent of the population sample were comprised of moderately large individuals ranging from 56 to 84 mm long. It is noteworthy that semiquantitative methods were sufficient to retrieve even some individuals <10 mm long, reflecting slow, careful searching of quadrats by divers.

Table 9
Percent Species Abundance and Frequency of Occurrence Based on Quantitative Samples near Post Creek, Lower Ohio River, October 1995

Species	Subsite 1		Subsite 2		Total	
	Abun	Freq	Abun	Freq	Abun	Freq
F. ebena	35.71	90.00	51.67	100.0	44.50	95.00
O. reflexa	19.39	80.00	13.33	90.00	16.06	85.00
Q. pustulosa	12.24	80.00	13.33	80.00	12.84	80.00
E. lineolata	6.12	50.00	10.00	80.00	8.26	65.00
Q. quadrula	6.12	40.00	2.50	20.00	4.13	30.00
A. p. plicata	5.10	30.00	1.67	20.00	3.21	25.00
C. tuberculata	3.06	20.00	1.67	20.00	2.29	20.00
T. truncata	2.04	10.00	2.50	20.00	2.29	15.00
Q. metanevra	4.08	40.00	0.83	10.00	2.29	25.00
P. alatus	2.04	10.00	0.83	10.00	1.38	10.00
M. nervosa	2.04	20.00	0.83	10.00	1.38	15.00
T. verrucosa	1.02	10.00	0.00	0.00	0.46	5.00
E. crassidens	1.02	10.00	0.00	0.00	0.46	5.00
O. olivaria	0.00	0.00	0.83	10.00	0.46	5.00
Total species	13		12		14	
Total individuals	98		120		218	
Total quadrats	10		10		20	
% Individuals <30 mm	20.40		16.70		18.30	
% Species <30 mm	53.80		33.30		57.10	
Menhinick's index	1.31		1.09		0.95	
Species diversity (H')	2.00		1.59		1.82	
Mean density	39.20		48.00		43.60	
Standard error	4.50		4.96		4.94	
Equitability	0.68		0.57		0.59	

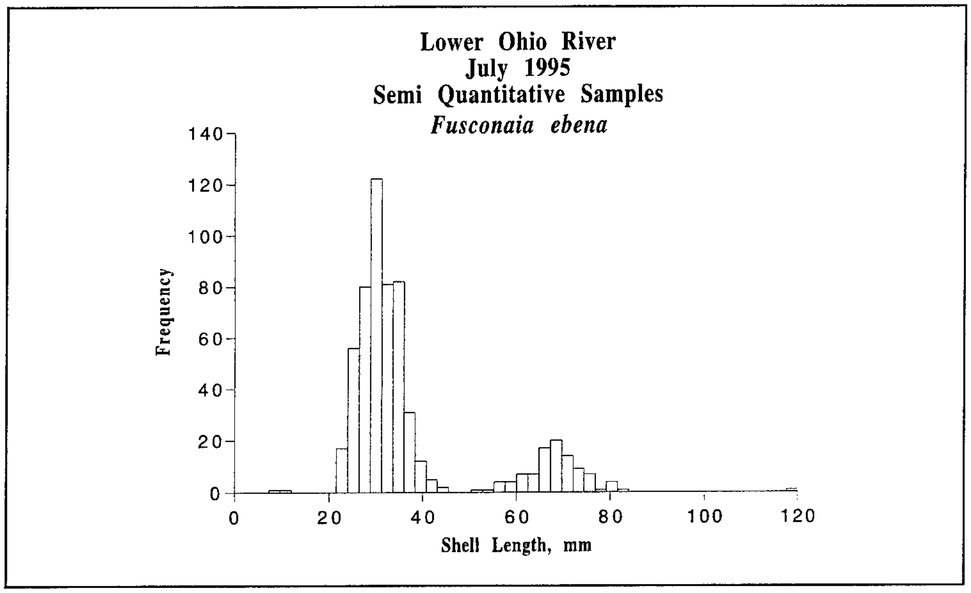


Figure 3. Length frequency histogram for *Fusconaia ebena* in semiquantitative samples, Lower Ohio River, July 1995

Demography of *F. ebena* from July quantitative samples at Olmsted is shown in Figure 4. Even more than semiquantitative samples, a length frequency histogram based on quantitative samples of substrate with mussels showed this population was heavily dominated by the 1990 year class. This cohort comprised approximately 95, 90, and 70 percent of the population at Sites I, II, and III, respectively (Figures 5 and 6). Site IV, located at approximately the farshore limit of the mussel bed, had only a few unionids; demography of *F. ebena* at Site IV was not characteristic of the bed (Figure 6).

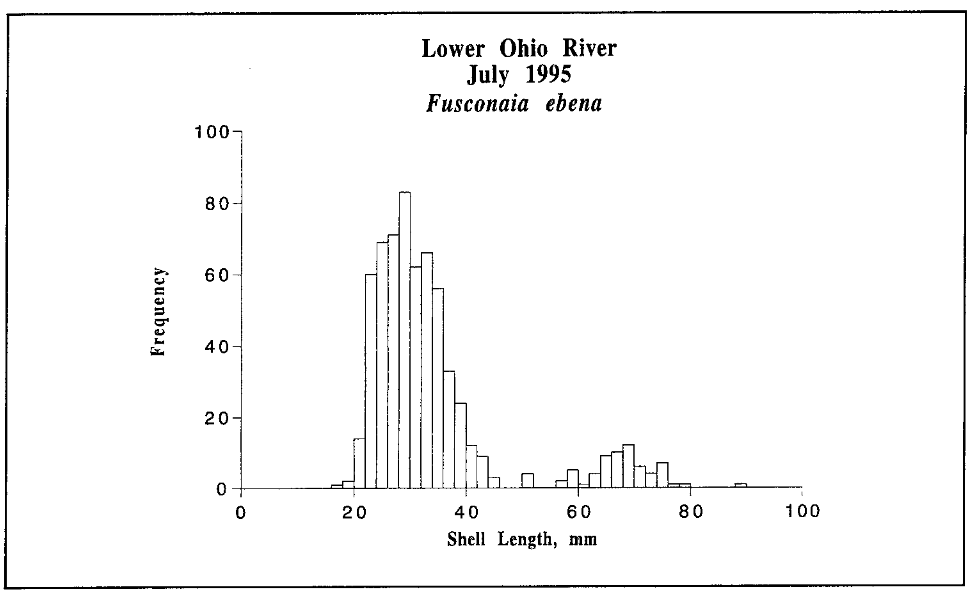
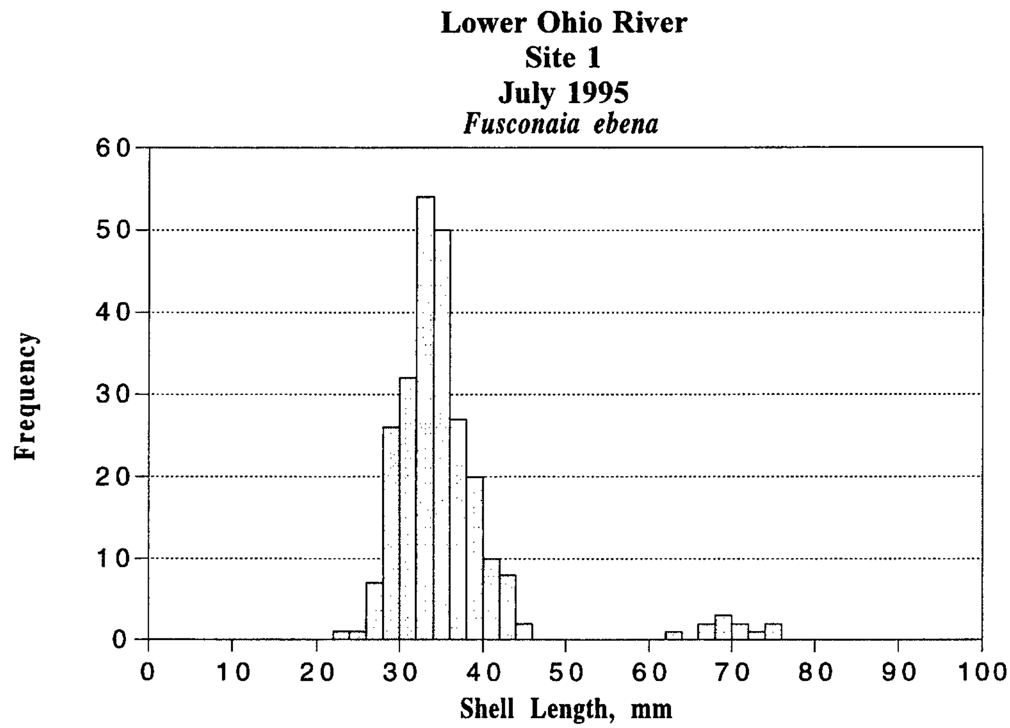


Figure 4. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River, July 1995



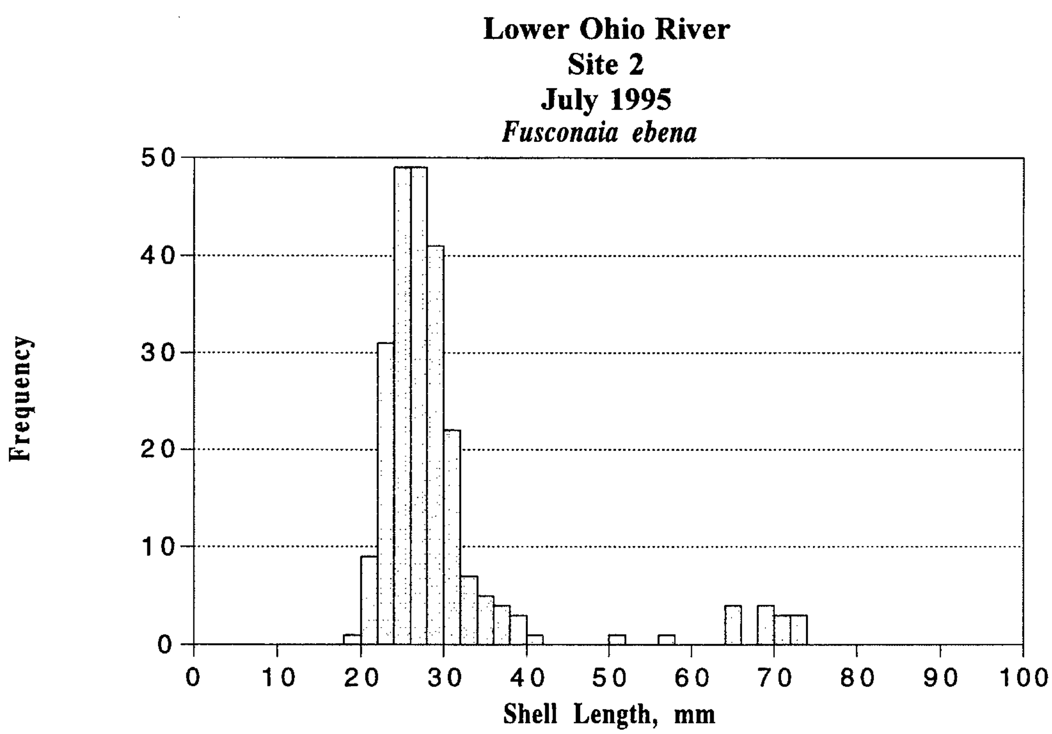


Figure 5. Length frequency histograms for *Fusconaia ebena* at Sites 1 and 2, Lower Ohio River, July 1995

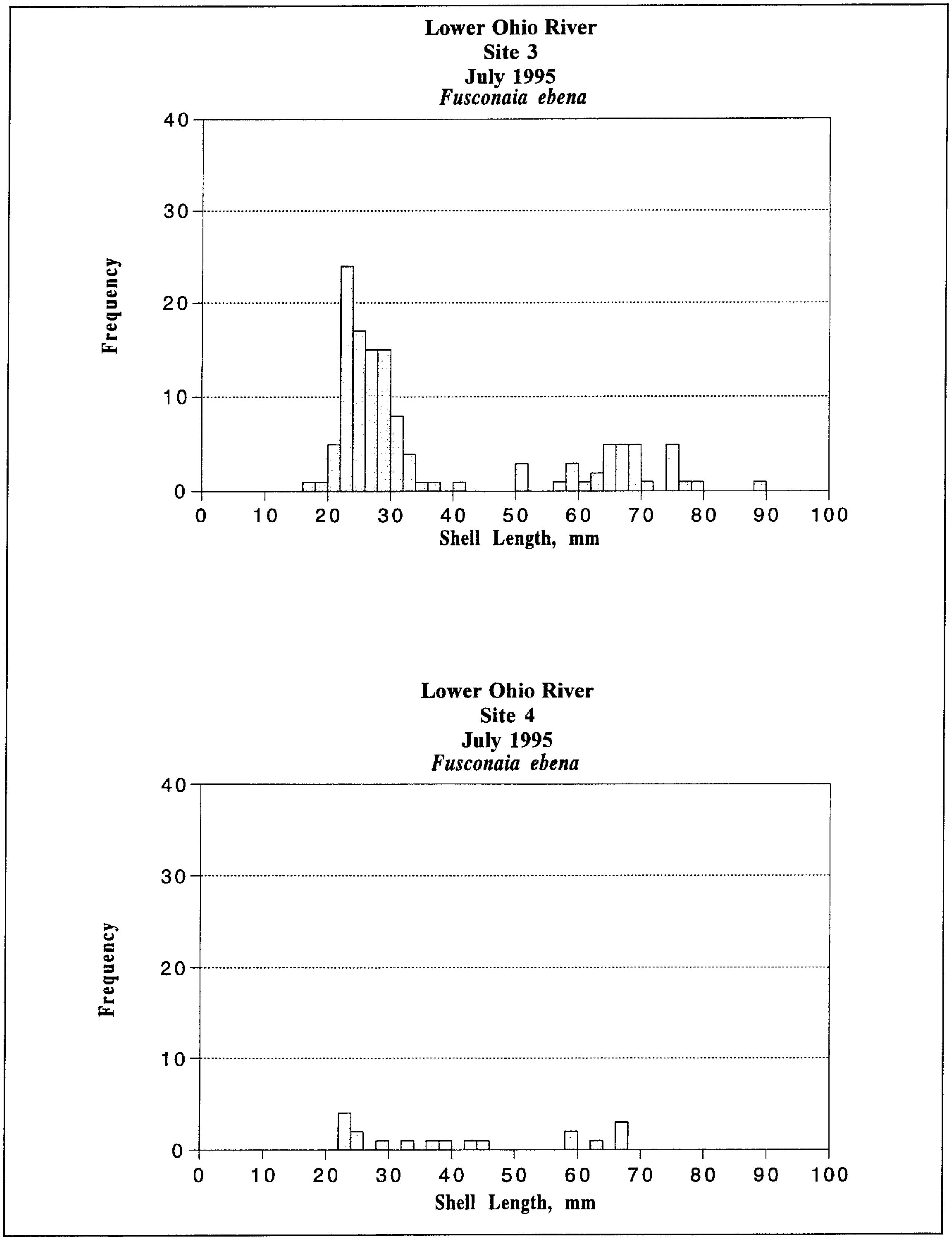


Figure 6. Length frequency histograms for *Fusconaia ebena* at Sites 3 and 4, Lower Ohio River, July 1995

Species other than *F. ebena* were not collected in sufficient numbers to warrant detailed analysis of population size structure. However, the prevalence of 20- to 40-mm mussels among *Q. pustulosa*, *Q. quadrula*, and *O. reflexa* suggests that strong 1990 recruitment of *F. ebena* characterized other species as well. Shell-length frequency histograms for several subdominant species are shown in Figures 7 through 10.

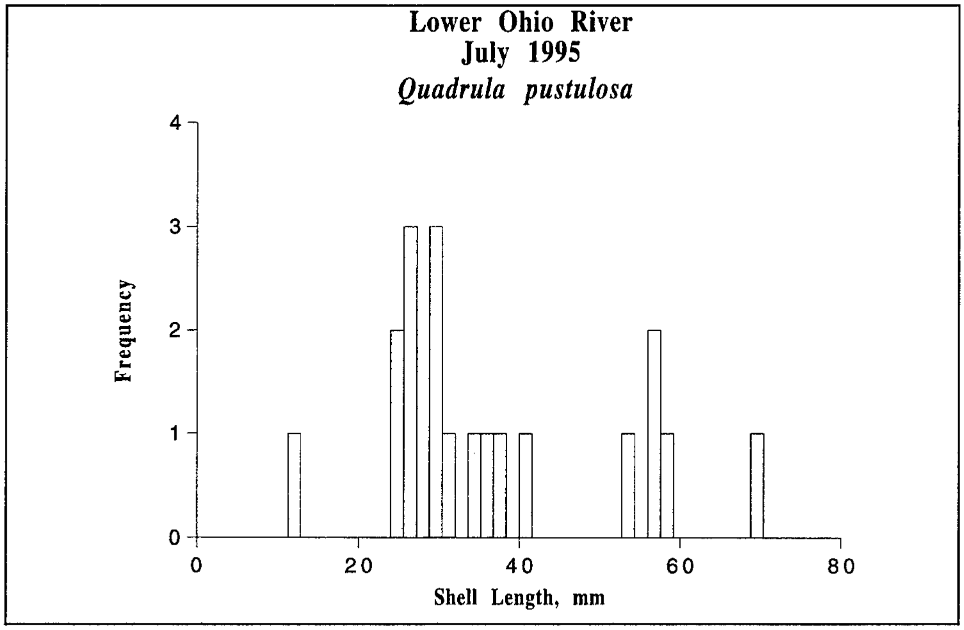


Figure 7. Length frequency histogram for *Quadrula p. pustulosa*, Lower Ohio River, July 1995

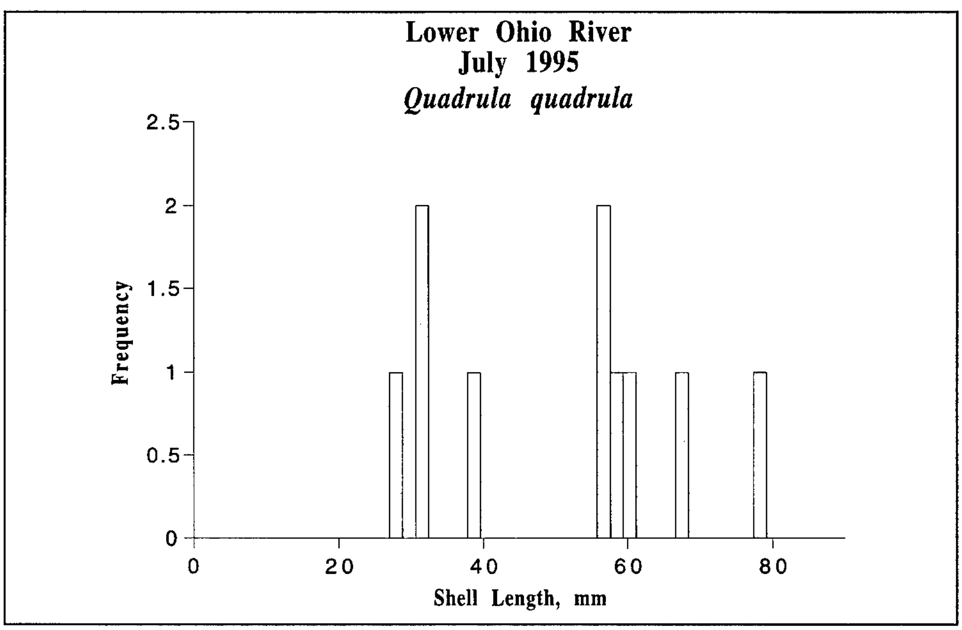


Figure 8. Length frequency histogram for *Quadrula quadrula*, Lower Ohio River, July 1995

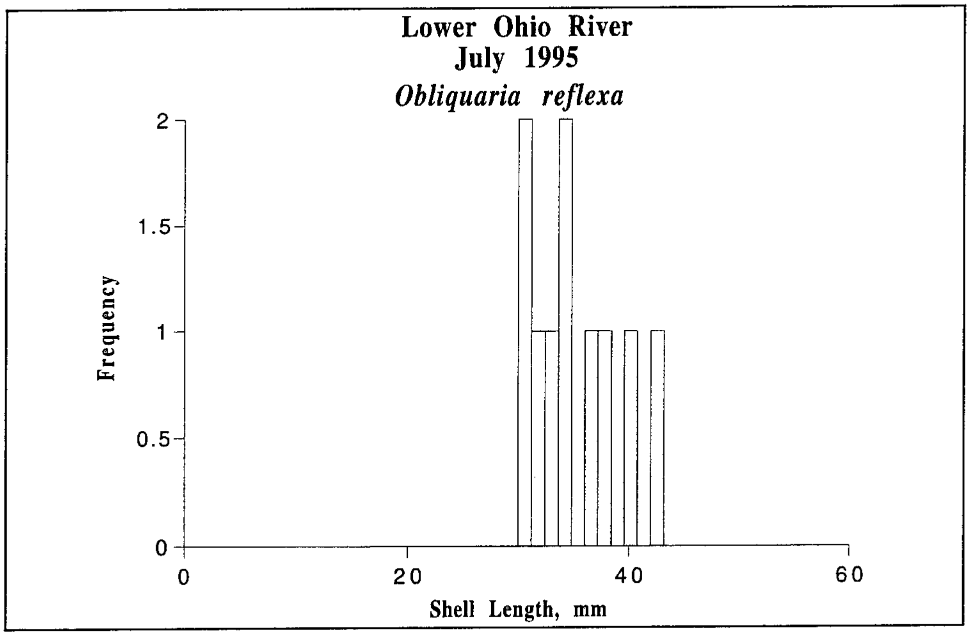


Figure 9. Length frequency histogram for *Obliquaria reflexa*, Lower Ohio River, July 1995

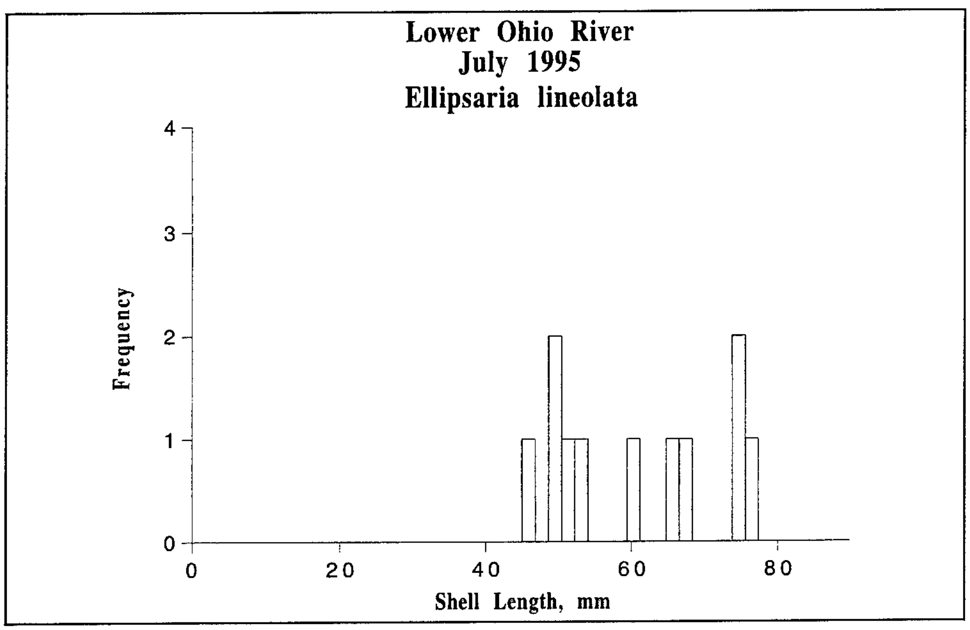


Figure 10. Length frequency histogram for *Ellipsaria lineolata*, Lower Ohio River, July 1995

Close inspection of the size structure of the *F. ebena* population revealed differences among Sites I, II, and III involving the length of the dominant 1990 cohort. At Site I, the 1990 year class of *F. ebena* had an average length of 34.2. At Site I, 94 percent of the population was of this year class, which ranged from 26 to 44 mm long. At Site II, approximately

1,500 ft upstream and slightly nearshore of Site I, the 1990 cohort of *F. ebena* had an average length of 26.9 mm. Ninety percent of the population was of this year class, which ranged from 20 to 38 mm long. Site III was approximately 1,250 ft upstream and slightly nearshore of Site II. At Site III, the average length of the 1990 cohort was similar to that observed at Site II. The 1990 cohort was less dominant at Site III than at Sites I and II. At Site III, approximately 70 percent of the population fell within the length range of this cohort (20 to 34 mm at that site). These intersite differences in the size of the 1990 cohort of *F. ebena* were associated with intersite differences in the extent to which *D. polymorpha* infested native unionids. This effect of *D. polymorpha* on *F. ebena* growth will be presented in more detail later.

Mussels ranging from 46 to 60 mm were absent at most sites. Mussels ranging from approximately 60 to 76 mm long were somewhat abundant at all sites, accounting for a second peak in the length frequency histograms. Indeed, these individuals comprised 17 percent of the population at Site 3. These moderately large *F. ebena* probably represent the 1981 cohort that heavily dominated this population from when it was first sampled in 1983 (Payne and Miller 1989) until the appearance of the 1990 cohort in the 1991 samples (Payne, Miller, and Shafer 1994).

Site IV yielded only 18 *F. ebena* by virtue of being slightly nearshore of the limit of the moderate- to high-density portion of the mussel bed. Some individuals of both the 1990 and 1981 cohorts appeared to be present at Site IV.

Substratum and zebra mussel density differed between Site I versus II and III. Site I was characterized by sandy substratum with only a little coarser grained material. Consequently, zebra mussel density was lower at Site I than at Sites II and III. The latter sites had substratum of sandy gravel with some cobble.

In October 1995 at Olmsted, size demography of the *F. ebena* population based on quantitative sampling (Figures 11 and 12) was similar to that observed in July. The 1990 cohort was heavily dominant at all three sites (>90 percent of the population, and thus, approximately 80 percent of the entire unionid community). This year class was comprised of individuals ranging from 24 to 39 mm long at Sites I and II (average length of approximately 30 mm). However, at Site III individuals of this young cohort were slightly larger, ranging from 28 to 43 mm and with average length of approximately 35 mm. The 1981 cohort was still evident from the group of individuals ranging in length from 60 to 76 mm.

Recent recruitment of *F. ebena* at Post Creek (Figure 13) was similar to that at Olmsted (Figures 11 and 12). The 1990 cohort at Post Creek ranged from 26 to 40 mm, with average length of 34 mm. A few more recent recruits (probably 1994 year class) were indicated by the presence of some mussels 10 to 12 mm long.

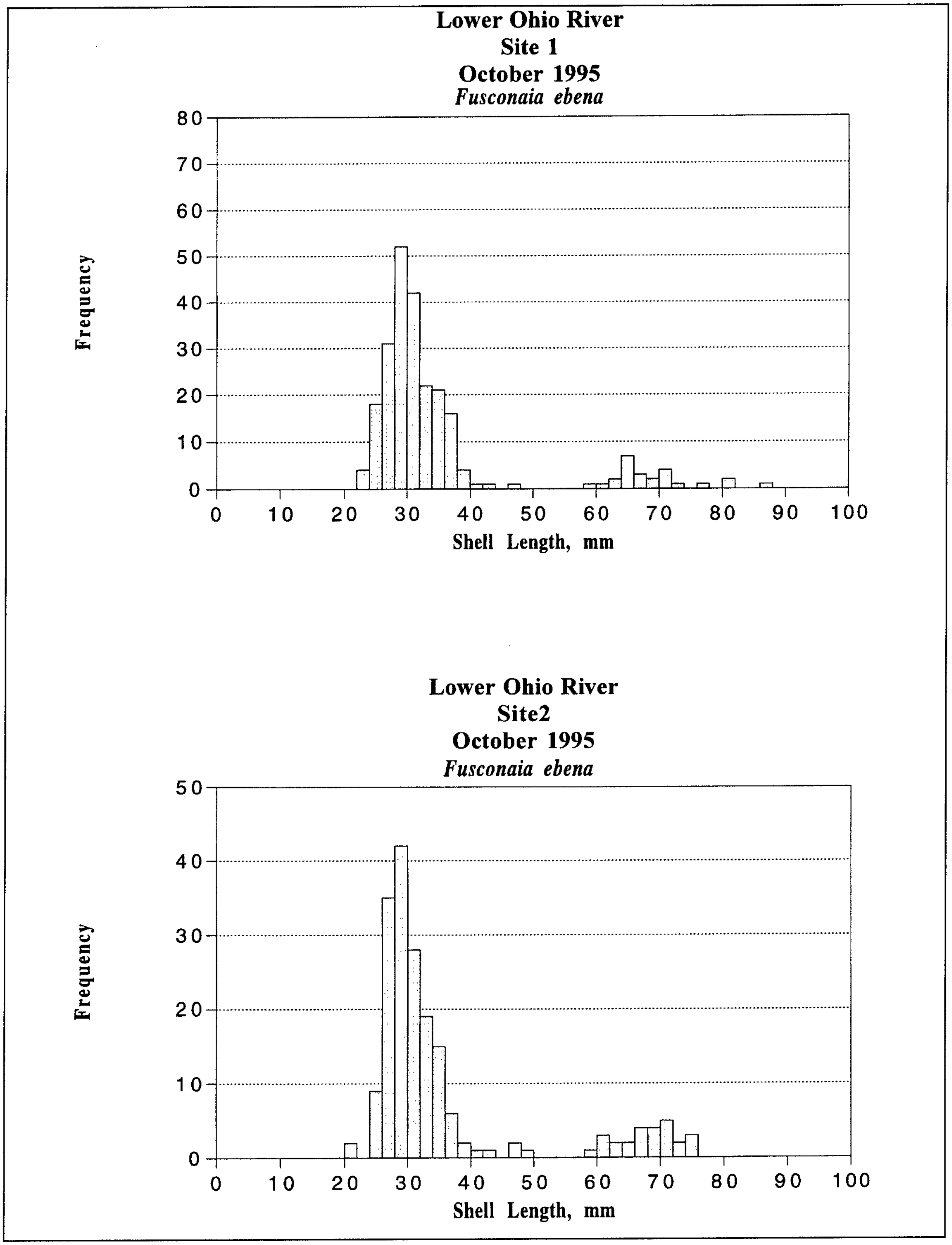


Figure 11. Length frequency histograms for *Fusconaia ebena* at Sites 1 and 2, Lower Ohio River, October 1995

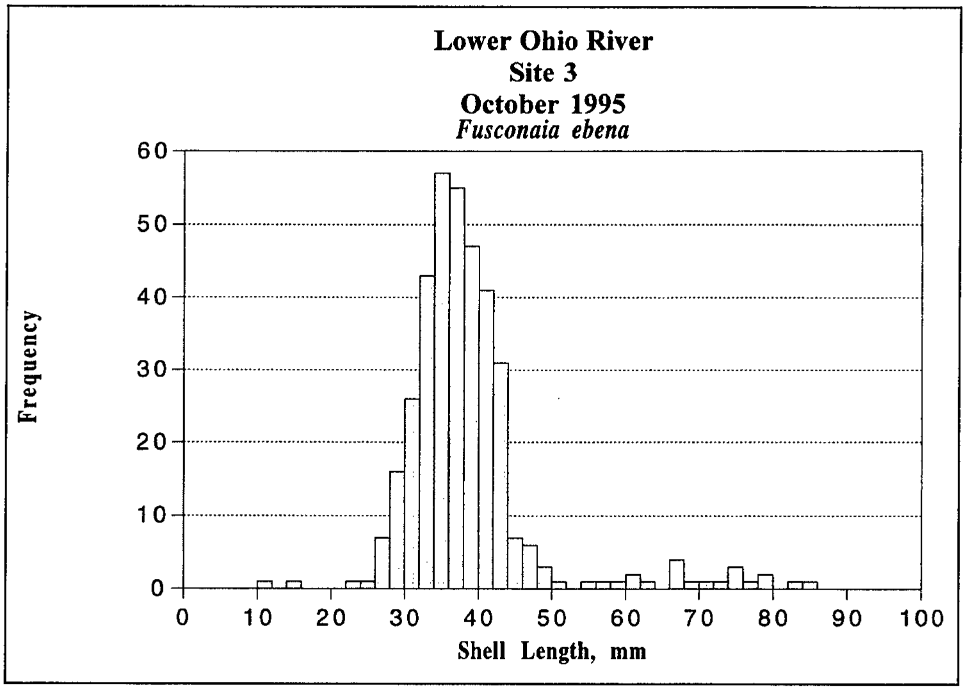


Figure 12. Length frequency histogram for *Fusconaia ebena* at Site 3, Lower Ohio River, October 1995

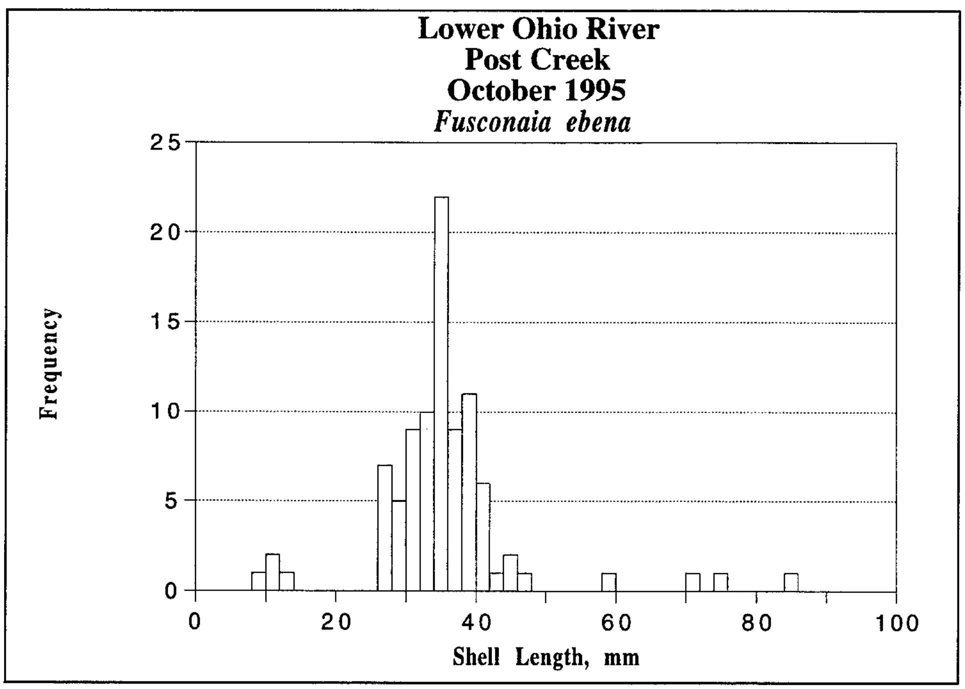


Figure 13. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River near Post Creek, October 1995

Nonindigenous species. Density of the Asian clam, *Corbicula fluminea*, was low at all Olmsted sites in July 1995. Estimates made at the four quantitative sites showed that the average density of *C. fluminea* ranged from less than 1 to 57 individuals per square meter (Table 2). The size structure of the *C. fluminea* population was simple (Figure 14). Essentially, the population consisted of a single cohort of animals with average length of approximately 15 mm, ranging mostly from 10 to 18 mm.

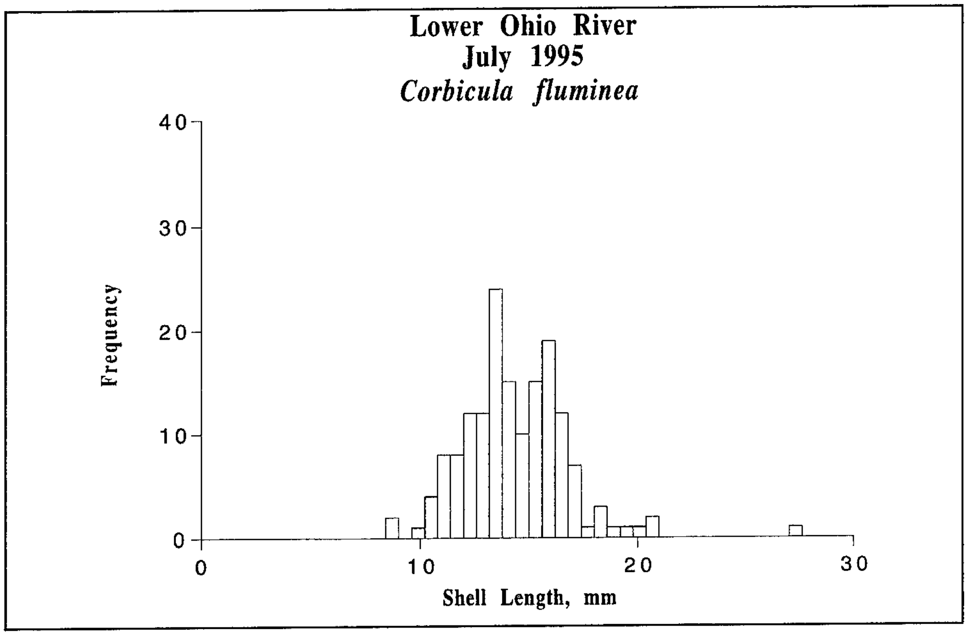


Figure 14. Length frequency histogram for *Corbicula fluminea*, Lower Ohio River, July 1995

In July 1995, infestation of native mussels by the zebra mussel, *Dreissena polymorpha*, was substantial. Most native mussels had several *D. polymorpha* attached to their shells (Table 10). Only 6.5 percent of all unionids gathered in semiquantitative samples were free of attached zebra mussels; 66.1 percent had 1-10 attached zebra mussels. Unionids with 11-50 attached zebra mussels comprised 18.8 percent of the community. Native mussels with >50 attached zebra mussels comprised 8.6 percent of the community.

Infestations of native unionids by *D. polymorpha* varied among quantitative sites in July 1995. Divers described substratum at Sites 1, 2, and 3 (those sites with moderate to high unionid density) as lightly infested by zebra mussels (Site 1, a sandy substratum) to heavily infested by zebra mussels (Sites 2 and 3, coarse substratum). The growth of the 1990 cohort of *F. ebena* appeared to be related to these infestation differences. For example, at Site 1, few zebra mussels infested the 1990 cohort (Figure 15). Most young *F. ebena* had 1-4 live zebra mussels attached to their shells. A similar assessment at Site 3 showed that most young *F. ebena* had 10-50 live zebra mussels attached to their shells (Figure 16). As

Table 10
Summary of Results of Semiquantitative Sampling at Olmsted, Lower Ohio River, July 1995

Site No.	Quadrat No.	No. of Mussels	Density	Number of Attached Zebra Mussels			
				0	1-10	11-50	>50
1	1	2	8	0	0	2	0
1	2	4	16	0	1	3	0
2	1	19	76	0	12	5	2
2	2	8	32	0	5	1	2
4	1	1	4	0	0	0	1
4	2	0	0	0	0	0	0
4	3	34	136	0	9	16	9
4	4	15	60	0	10	5	0
5	1	2	8	0	1	0	1
5	2	5	20	0	1	3	1
6	1	15	60	0	10	3	2
6	2	16	64	0	9	2	5
6	3	14	56	0	2	8	4
6	4	15	60	0	1	7	7
6	5	0	0	0			0
6	6	2	8	1		1	0
7	1	22	88		20	2	0
7	2	33	132	3	25	4	1
7	3	1	4	1			0
7	4	2	8		2		0
8	5	30	120		27	1	2
8	6	33	132	5	26	2	0
8	7	3	12		1	1	1
8	8	3	12		2	1	0
8	9	8	32	1	7	0	0
8	10	2	8	2	0	0	0
8	11	2	8	0	2	0	0
8	12	2	8	0	2	0	0
9	1	5	20	0	2	1	1
9	2	3	12	0	3	0	0
9	3	51	204	2	43	2	4
9	4	52	208	2	43	4	3
10	1	1	4	0	0	1	0

(Continued)

Table 10 (Concluded)							
				Number of Attached Zebra Mussels			
Site No.	Quadrat No.	No. of Mussels	Density	0	1-10	11-50	>50
10	2	2	8	0	1	1	0
10	3	10	40	0	0	0	0
10	4	1	4	0	0	0	0
10	5	3	12	0	1	2	0
10	6	1	4	0	0	1	0
10	7	23	92	0	20	3	0
10	9	5	20	1	4	0	0
10	10	6	24	0	3	3	0
10	11	19	76	1	12	6	0
10	12	12	48	1	6	5	0
11	1	1	4	0	0	1	0
11	3	5	20	0	0	5	0
11	4	5	20	0	0	5	0
11	5	1	4	0	0	1	0
11	6	1	4	0	0	0	1
11	7	9	36	0	3	4	2
11	8	6	24	0	4	0	2
11	9	49	196	1	43	1	2
11	11	35	140	13	15	5	2
11	12	22	88	3	16	2	1
14	1	2	8	0	2	0	0
14	2	2	8	0	0	0	0
14	3	3	12	0	3	0	0
14	4	4	16	0	4	0	0
14	5	4	16	0	3	1	0
14	6	3	12	0	3	0	0
14	7	5	20	0	3	1	1
14	8	5	20	0	4	1	0
14	9	17	68	5	11	1	0
14	10	9	36	1	8	0	0
14	11	2	8	0	2	0	0
Total Mussels		677		43	437	124	57
% Infested				6.5	66.1	18.8	8.6
Mean density		10.58					

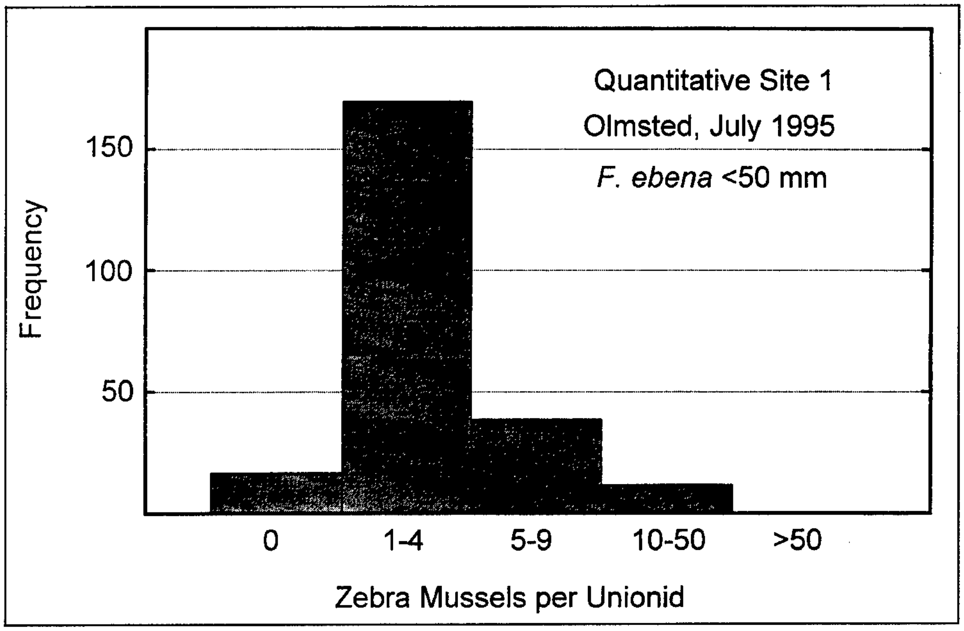


Figure 15. Infestation of small *Fusconaia ebena* at Site 1 by the zebra mussel, *Dreisseria polymorpha*

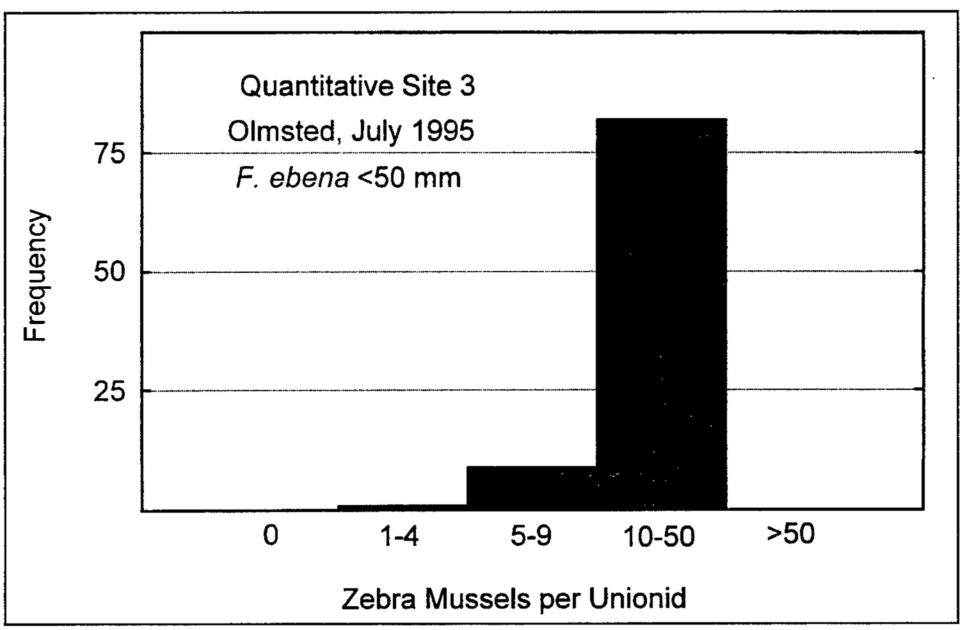


Figure 16. Infestation of small *Fusconaia ebena* at Site 3 by the zebra mussel, *Dreissena polymorpha*

shown in Figures 15 and 16, the 1990 cohort of *F. ebena* at Sites 1 and 3 had an average length of approximately 32 and 25 mm, respectively. These intersite differences probably reflect recent growth-rate differences associated with low versus high levels of zebra mussel infestation.

Density of the zebra mussel, *Dreissena polymorpha*, was related to elevation in a pattern different from that observed for unionids (Figure 17). As with native unionids, density of zebra mussels was limited in the farshore direction by lack of suitable, stable substratum. Approaching the channel, substratum is predominantly erosional sand. Neither unionids nor zebra mussels are dense beyond approximately the 267-ft elevation contour. However, unlike unionids, zebra mussel density remained high nearshore of the 279-ft elevation contour. Indeed, almost every sample nearshore of the 279-ft elevation contour had high zebra mussel density. Several records of zero density were made farshore of that contour. Overall, zebra mussel density ranged from 0 to slightly greater than 11,000 individuals per square meter.

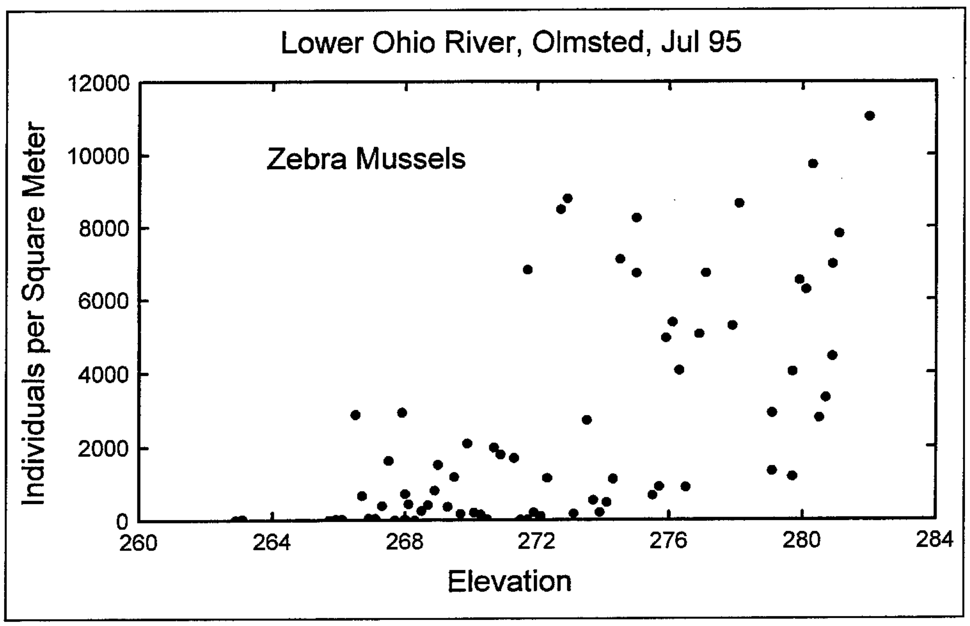


Figure 17. Zebra mussel density in relation to elevation, Lower Ohio River, July 1995

It was apparent during onsite processing of quantitative samples of unionids that *Dreissena* density was markedly less in October 1995 than it had been in July. Native unionids taken in quantitative samples were assessed for zebra mussel infestation level. At Site 1, only 4 of 200 unionids assessed had live zebra mussels attached. However, 194 individuals had tufts of byssal threads that had once held live zebra mussels. At Site 2, no live zebra mussels were observed attached to 117 individuals inspected. However, all but one of these individuals had zebra mussel byssal tufts. At Site 3, 22 of 186 inspected unionids had live zebra mussels attached. Tufts of byssal threads were observed on 173 of these 186 mussels.

Because of the low density of live zebra mussels, a single set of five 0.25-m^2 quantitative samples were taken specifically for zebra mussels. The mean density of zebra mussels was only 73.6 individuals per square meter in October 1995 versus the several thousand per square meter observed on average in July 1995.

In addition, the size structure of the zebra mussel population was markedly different in October from in July due to natural mortality of the 1994 year class between July and October (Figure 18). In July, the dense population was comprised only of a single cohort of large individuals with average length of approximately 18 mm. These individuals were the surviving reproductive cohort of the 1994 year class that was extremely dense in September 1994. By October 1995, the 1994 year class had died (except for a few individuals 20 to 26 mm long), and the population was comprised essentially of only 1995 recruits. This new year class had an average length of approximately 7 mm, with nearly all mussels measuring less than 10 mm. The density of this population decreased by nearly two orders of magnitude from July to October 1995, and approximately three orders of magnitude from September 1994 to October 1995.

Like the Olmsted location, zebra mussel density was low in October at the Post Creek sites. Native unionids collected by qualitative methods showed low-infestation levels. Thirty-four of 158 mussels collected at one site had live zebra mussels attached. All but two had zebra mussel byssal tufts attached, consistent with the recent death of the dense older cohort of *F. ebena* present at Olmsted in July but not October. At the second Post Creek qualitative site, 33 of 199 native mussels had live zebra mussels attached to them, while a total of 184 individuals had byssal tufts attached. Zebra mussel density, based on five 0.25-m^2 quantitative samples taken for the sole purpose of that assessment, equaled 66.4 individuals per square meter. Like Olmsted, virtually all zebra mussels at Post Creek were small. The maximum shell length was 20.2 mm, and the average length was 8.8 mm, reflecting the recent mortality of the oldest, largest, and most dense cohort.

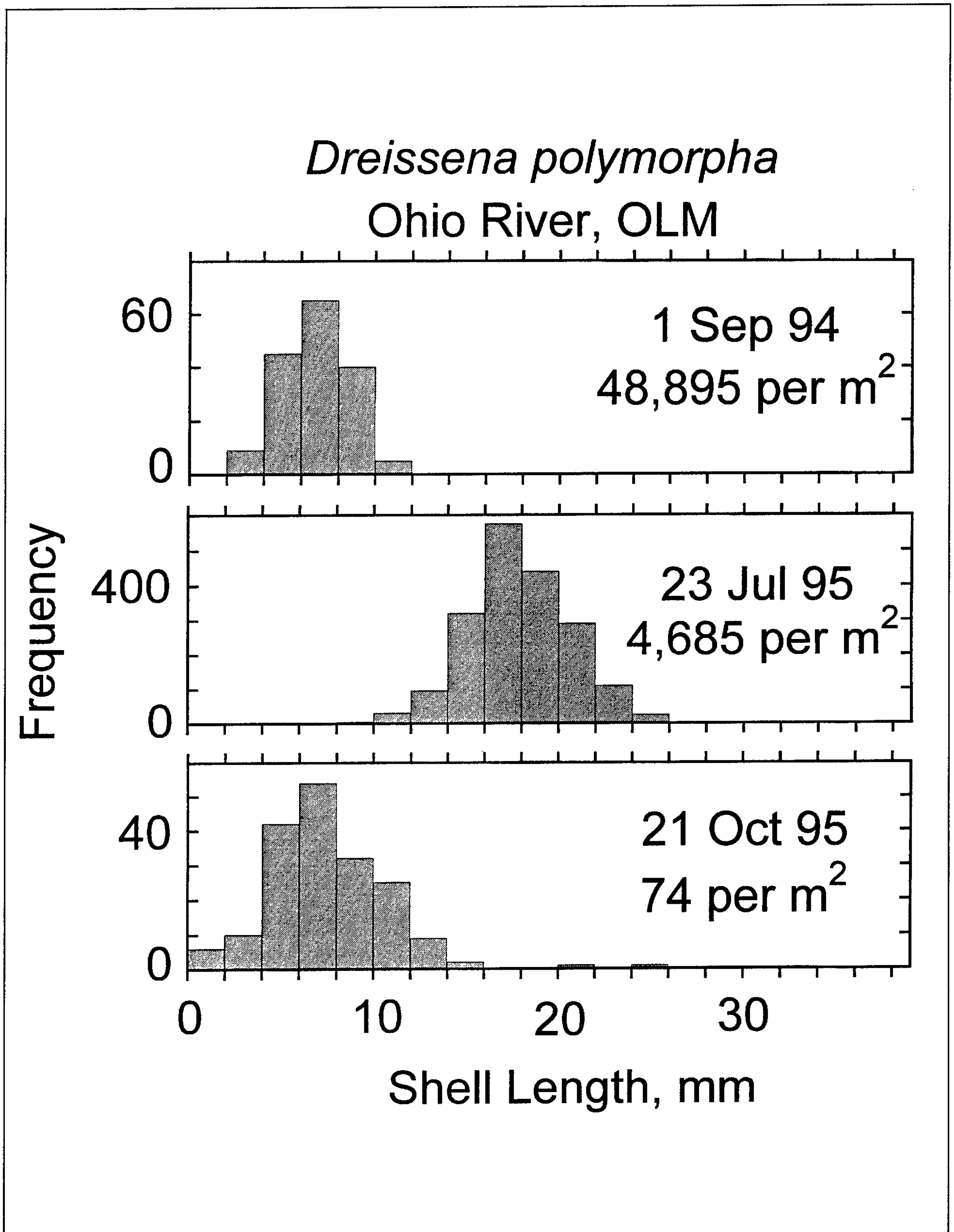


Figure 18. Length frequency histograms showing replacement of 1994 cohort of *Dreissena polymorpha* by 1995 cohort between July and October 1995

3 1996 Studies

Sites and Methods

Sampling was conducted in August at the Olmsted location and in October at both the Olmsted and Post Creek locations.

Studies were performed downstream of the Olmsted Locks and Dam Project between RM 967 and 969 from 13 to 16 August 1996. River stage (Cairo gauge) was used to position the dive boat over appropriate bottom surface elevations. Stage ranged from 294.6 to 295.4 ft during August sampling. Semiquantitative samples for native mussels and quantitative samples of zebra mussels were collected from nine locations of the dive boat over the mussel bed (Table 11). At each boat position, one diver moved nearshore and one diver moved farshore to positions approximately 100 ft from the boat. Substratum and density of unionids, *Dreissena*, and *Corbicula* were described by divers using a two-way communication system as they moved to their final positions away from the boat. Semiquantitative samples of unionids consisted of a search by feel by each diver of two adjacent 0.25-m^2 quadrats. In addition at these sites, two quantitative samples of *Dreissena* were collected by each diver using a 0.0625-m^2 quadrat.

Quantitative samples of native mussels involved removal of substratum with mussels from 10 replicate 0.25-m^2 quadrats at each of five sites (Table 11). Substratum was winched to the surface, transported to shore, and processed through a nested sieve series with the smallest mesh equal to 6.4 mm.

In addition, three qualitative searches were made for unionids (Table 11). Two searches involved collection (by feel) of all unionids regardless of species by the incremental method of collecting three bags of five mussels followed by nine bags of 20 mussels. This incremental sampling yields a species-sampling effort curve. The remaining search involved collection selectively of species other than *F. ebena*, the heavily dominant species. This latter technique has been used successfully to obtain locally rare species, including the Federally endangered species *Plethobasus cooperianus*.

Table 11
Locations and Elevations of August 1996 Samples from a Mussel Bed in the Lower Ohio River near Olmsted, IL

Latitude (degrees North)	Longitude (degrees West)	Samples	Elevation (feet above mean sea level)
3708.653	8905.321	2-1 near (n = 2) 2-1 far (n = 2)	268 266
3709.689	8905.389	2-2 near (n = 2) 2-2 far (n = 2)	274 272
3709.469	8905.500	4-1 near (n = 2) 4-2 far (n = 2) Quantitative I (n = 10)	269 262 268
3709.376	8905.554	4-2 near (n = 2) 4-2 far (n = 2) Quantitative II (n = 10)	270 262 265
3709.229	8905.603	5-1 near (n = 2) 5-1 far (n = 2)	271 265
3709.296	8905.612	5-2 near (n = 2) 5-2 far (n = 2)	275 269
3708.946	8905.730	7-2 near (n = 2) 7-2 far (n = 2) Quantitative III (n = 10)	275 275 275
3708.890	8905.682	7-1 near (n = 2) 7-1 far (n = 2) Quantitative IV (n = 10)	268 262 267
3708.472	8905.833	9-1 near (n = 2) 9-1 far (n = 2)	271 270
3708.348	8905.878	10-1 near (n = 2) 10-1 far (n = 2)	268 269
3708.330	8905.900	Quantitative V (n = 10) Qualitative I	269 269
3708.267	8905.889	Qualitative II Qualitative III	270 270

Studies were again conducted at Olmsted on 24 October 1996. Ten replicates of 0.25-m^2 quantitative samples were collected at three sites (Table 12). Quantitative samples for zebra mussels were collected from two quadrats at each of these three sites. On 25 October 1996, three sites at the Post Creek location in Pool 53 were similarly sampled (Table 12).

Table 12 Locations and Elevations of October 1996 Samples from Mussel Beds in the Lower Ohio River near Olmsted and Post Creek, IL			
Latitude (degrees North)	**Longitude (degrees West)**	**Samples**	**Elevation (feet above mean sea level)**
3708.829	8905.861	OLM Quantitative I (n = 10) OLM Quantitative II (n = 10) OLM Quantitative III (n = 10)	278 278 278
3713.820	8857.175	PC Quantitative I (n = 10) PC Quantitative II (n = 10) PC Quantitative III (n = 10)	No record No record No record

Results

Mussel density and spatial distribution in the Olmsted bed

The 18 semiquantitative sampling sites ranged in location from approximately RM 967.9 to 968.1 and spanned river bottom elevations from 262 ft nearshore to 276 ft farshore. The nearshore and farshore limits of the mussel bed generally correspond to the 279- and 267-ft contour lines, respectively (Payne and Miller 1997). Thus, sampling in August 1996 was focused on the middle to farshore portion of the bed (Figure 19).

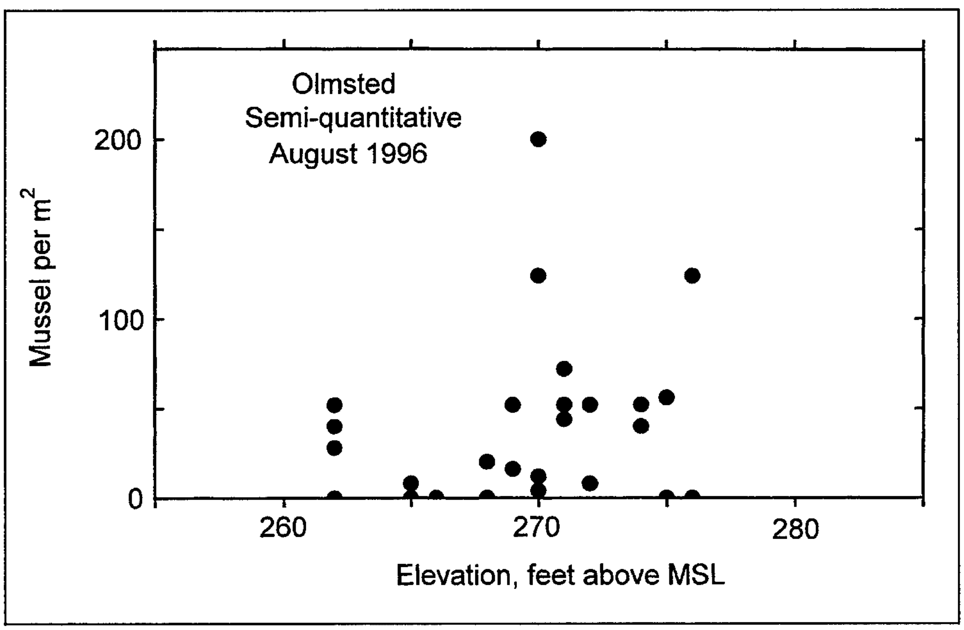


Figure 19. Native mussel density in relation to elevation, Lower Ohio River, August 1996

Elevation contours do not precisely correspond to the limits of the mussel bed. For example, two samples beyond the general farshore limit at elevation 267 supported dense populations of unionids (Table 13, Figure 19). One of these sites, at elevation 262 and RM 966.9, yielded 40 and 28 unionids per square meter from two semiquantitative samples. The diver described the community at this site as one of exclusively small *F. ebena*. Similarly, a second site at elevation 262 and RM 967.9 yielded estimates of 52 and 36 unionids per square meter from the two semiquantitative samples. Once again, the diver described the community at this location as being exclusively small *F. ebena*. Both locations appeared to represent moderate- to high-density patches of relatively young *F. ebena* but probably were farshore of the main mussel bed judging from a lack of large mussels at both sites. Nonetheless, patches of suitable substrate occur beyond the 267-ft contour that can support recruits for at least a few years.

Considerable variation exists in mussel density within the general limits of the bed. Sixteen of 26 semiquantitative samples collected between elevations 268 and 276 supported greater than 20 unionids per square meter Twelve of these supported more than 50 unionids per square meter. Three of the quadrats from high-density sites yielded more than 100 mussels per square meter. Only 4 of the 26 quadrats collected between elevations 268 and 276 yielded no mussels. Conversely, half of the samples collected from elevations 262 to 266 had no mussels. Only 4 of 10 samples collected beyond the 267-ft contour yielded moderate densities (and these, as noted above, were especially dominated by small *F. ebena*). Thus, despite considerable variability, the 267 elevation roughly defined the farshore limit of the bed during August 1996 sampling.

Despite these general patterns, patchiness of mussel density is substantial. Only a high degree of replicated sampling allows patterns to be discerned. Thus, quantitative sampling involving 10 replicates per site was required to obtain accurate estimates of average mussel density at a site. In contrast, two semiquantitative samples per site can yield greatly disparate results. For example, one site semiquantitatively sampled at elevation 275.5 yielded an estimate of 124 individuals per square meter from one quadrat and zero individuals per square meter from the adjacent quadrat.

With respect to substratum, semiquantitative sampling did not reveal a clear pattern of unionid-to-substratum relationship (Figure 20). Although four of six quadrats sampled in sand yielded no mussels, two such quadrats indicated densities of 200 and 124 individuals per square meter. Moderate and high-density estimates were obtained in cobbley gravel, sandy gravel, gravelly sand, and sand.

Mussel density at the five sites quantitatively sampled in August 1996 ranged from zero to 111.6 individuals per square meter (Table 14). Site 1 was located at RM 966.7 at an elevation of 268 ft just upstream of sediment and water quality monitoring Buoy No. 2. Site 1 supported 52.8 mussels

Table 13
Summary of Results of Semiquantitative Sampling from 0.25-m² Quadrats, Olmsted Mussel Bed, Lower Ohio River, August 1996[1]

Site	Quad No.	Location	No. of Mussels	Mean Density	Number of Attached Byssal Threads				Number of Attached Zebra Mussels			
					0	1-10	11-50	>50	0	1-10	11-50	>50
2	1	NA	0		0	0	0	0	0	0	0	0
2	1	NB	0	0	0	0	0	0	0	0	0	0
2	1	FA	0		0	0	0	0	0	0	0	0
2	1	FB	0	0	0	0	0	0	0	0	0	0
3	2	NA	10		0	3	7	0	3	0	5	2
3	2	NB	13	11.5	2	0	11	0	2	2	6	3
3	2	FA	13		1	7	5	0	7	0	4	2
3	2	FB	2	7.5	0	0	2	0	0	0	1	1
4	1	NA	13		1	6	4	2	12	0	0	1
4	1	NB	14	13.5	1	9	4	0	11	2	0	1
4	1	FA	0		0	0	0	0	0	0	0	0
4	1	FB	0	0	0	0	0	0	0	0	0	0
4	2	NA	1		0	0	0	1	0	0	0	1
4	2	NB	3	2	1	0	0	2	1	0	0	2
4	2	FA	10		2	1	7	0	8	0	0	2
4	2	FB	7	8.5	0	1	6	0	4	0	0	3
5	1	NA	11		1	4	1	5	7	0	3	1
5	1	NB	13	12	3	4	6	0	5	4	1	3
5	1	FA	2		0	0	0	3	0	0	0	1
5	1	FB	0	1	0	0	0	0	0	0	0	0
5	2	NA	0		0	0	0	0	0	0	0	0
5	2	NB	1	0.5	0	0	1	0	1	0	0	0
5	2	FA	4		4	0	0	0	0	0	0	4
5	2	FB	3	3.5	1	0	2	0	0	1	1	1

(Continued)

[1] NA = Nearshore, Subsite A; NB = Nearshore, Subsite B: FA = Farshore, Subsite A; FB = Farshore, Subsite B.

Table 13 (Concluded)												
					Number of Attached Byssal Threads				Number of Attached Zebra Mussels			
Site	Quad No.	Location	No. of Mussels	Mean Density	0	1-10	11-50	>50	0	1-10	11-50	>50
6	1	NA	14		0	12	2	0	14	0	0	0
6	1	NB	15	14.5	0	12	2	1	15	0	0	0
6	1	FA	31		0	31	0	0	29	2	0	0
6	1	FB	0	15.5	0	0	0	0	0	0	0	0
9	1	NA	5		0	1	4	0	5	0	0	0
9	1	NB	6	5.5	2	4	0	0	6	0	0	0
9	1	FA	13		0	8	5	0	13	0	0	0
9	1	FB	9	11	1	4	4	0	9	0	0	0
9	2	NA	13		1	10	2	0	12	1	0	0
9	2	NB	18	15.5	0	14	4	0	18	0	0	0
9	2	FA	50		3	39	8	0	50	0	0	0
9	2	FB	31	40.5	2	21	7	1	31	0	0	0
Total mussels			325									
Total quadrats			36									

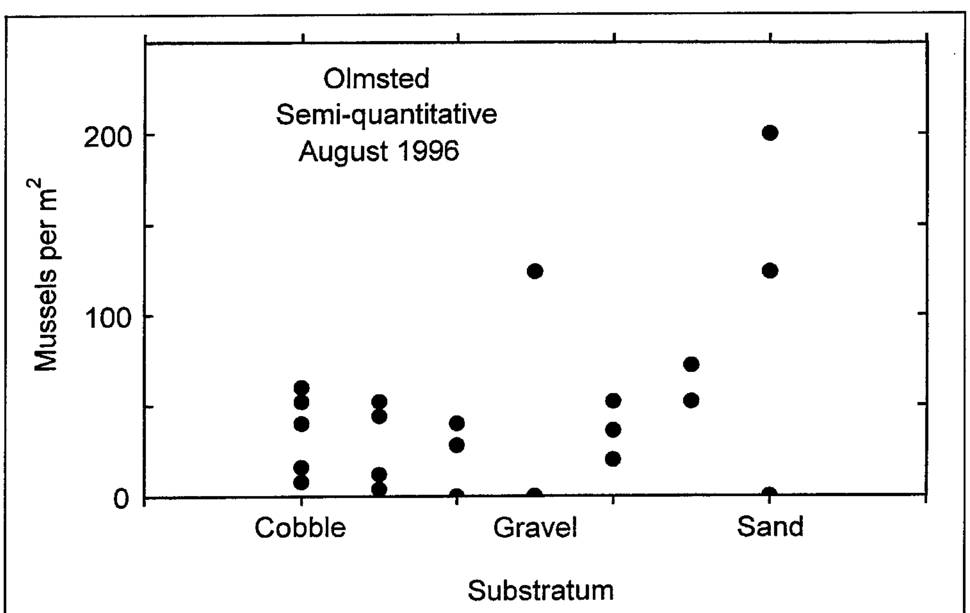


Figure 20. Native mussel density in relation to predominant substratum type, Lower Ohio River, August 1996

Table 14
Percent Species Abundance of Freshwater Mussels Collected in Quantitative Samples from the Lower Ohio River, August 1996

Species	Site Number 1	2	3	4	5	Total
F. ebena	91.67	71.11	0.00	75.00	90.32	88.58
Q. p. pustulosa	2.27	11.11	0.00	12.50	2.51	3.45
Q. metanevra	1.52	2.22	0.00	0.00	2.15	1.94
E. lineolata	0.00	2.22	0.00	0.00	2.51	1.72
Q. quadrula	0.00	8.89	0.00	0.00	0.00	0.86
A. p. plicata	1.52	0.00	0.00	0.00	0.72	0.86
Q. nodulata	0.76	0.00	0.00	12.50	0.36	0.65
M. nervosa	0..00	4.44	0.00	0.00	0.00	0.43
E. crassidens	0.76	0.00	0.00	0.00	0.36	0.43
O. olivaria	0.00	0.00	0.00	0.00	0.72	0.43
T. truncata	0.76	0.00	0.00	0.00	0.00	0.22
O. reflexa	0.00	0.00	0.00	0.00	0.36	0.22
T. donaciformis	0.76	0.00	0.00	0.00	0.00	0.22
Total species	8	6	0	3	9	13
Total individuals	132	45	0	8	279	464
% Individuals <30 mm	31.1	17.8	0	12.5	6.8	14.87
% Species <30 mm	62.5	33.3	0	33.3	22.2	53.84
Menhinick's index	0.69	0.89	0	1.06	0.53	0.6
Species diversity (H')	0.44	1.01	0	0.73	0.49	0.59
Equitability	0.34	0.53	0	0.8	0.35	0.33
Mean density	52.80	18.00	0.00	3.20	111.60	37.12
Standard error	12.49	3.50	0.00	0.75	24.72	15.33

per square meter. Site 2, at RM 966.9 and elevation 265 ft, supported 18.0 mussels per square meter. Site 3, at RM 967.4 and elevation 275, yielded no mussels from 10 replicate quadrats. Site 4, at RM 967.4 and elevation 267, had an average density of 3.2 mussels per square meter. Site 5, at RM 968.1 and elevation 269, supported 111.6 individuals per square meter. Site 3, with no mussels, was within the 267 to 279 elevation range that roughly defines the mussel bed in an area of the shoal that generally supports high densities of native unionids. The lack of mussels at Site 3 reflected the high degree of patchiness in mussel density that occurs within the bed.

The three sites quantitatively sampled at Olmsted in October 1996 all supported low to moderate densities of unionids; mean density ranged from 18.8 to 20.0 among the three sites (Table 15). Unlike quantitative sampling in August, when the five sites sampled were each separated by considerable distance, the three sites sampled in October intentionally were closely spaced. The dive boat was positioned at 3708.829 N and 8905.861 W (elevation 278), and Site 1 was sampled. Then the boat was slightly repositioned by letting out approximately 50 ft of anchor line, and Site 2 was sampled. The boat was similarly repositioned for Site 3. Thus, the three sites sampled quantitatively in October 1996 were essentially subsites of a single location. The consistency of density estimates among the three sites (means equal to 19.2, 20.0, and 18.8 individuals per square meter) reflected the proximity of the sites.

Native mussel community composition

Olmsted. Semiquantitative samples in August 1996 reflected the heavy dominance of F. *ebena* at Olmsted (Table 16). This species comprised 82.8 percent of the native mussel community. Fourteen species were represented among 325 individuals collected from the search-by-feel method within 0.25-m^2 quadrats. Diversity, due to the extreme dominance of *F. ebena*, was low at 0.86 (Shannon-Weaver index) and 0.78 (Menhinick's index). The extreme dominance of *F. ebena* was also reflected in low equitability. Equitability has a theoretical maximum value of 1.0, but only equaled 0.33 in this semiquantitative sample of the mussel community. Despite the increased risk of overlooking small mussels using a search-by-feel method, nearly 6 percent of all individuals collected were less than 30 mm long.

Community composition was not much different based on quantitative sampling in August 1996 at Sites 1-5 (Table 14). *Fusconaia ebena* comprised 88.6 percent of the community, ranging from 61.1 to 91.7 percent among the different sites of quantitative sampling. A total of 13 species were represented among the 464 individuals collected by quantitative methods. Diversity was low and averaged 0.59 (Shannon-Weaver index) and 0.60 (Menhinick's index) considered across all sites. Equitability was low, equaling 0.33 for all sites. The percentage of individuals less than 30 mm long was higher than in semiquantitative samples, equaling 14.9 percent for all sites (ranging from 6.8 percent at Site 5 to 31.1 percent at Site 1). More than half of the 13 species included at least one such recent recruitment, indicating a community-wide aspect of recently successful recruitment of native mussels.

Qualitative samples taken near quantitative Site 5 in August 1996 were heavily dominated by *F. ebena*. Thus, a low total number of species were obtained at the two sites where qualitative sampling was for all native mussels, regardless of species. At Site 1, seven species were represented among 180 mussels. All but 20 of these were *F. ebena*. Other species collected at Site 1 were *Quadrula metanevra* (11), *Obliquaria reflexa* (3), *Obovaria olivaria* (2), *Q. p. pustulosa* (2), and of special note, *Plethobasus cooperianus* (1). Slightly more species (11) were obtained at

Table 15
Frequency of Abundance and Frequency of Occurrence of Freshwater Mussels Collected near the Mouth of Post Creek, Lower Ohio River, October 1996

	Site Number							
	Subsite 1		Subsite 2		Subsite 3		Total	
Species	Abun	Freq	Abun	Freq	Abun	Freq	Abun	Freq
F. ebena	33.83	100.00	29.03	100.00	28.79	90.00	31.16	72.50
Q. pustulosa	26.32	70.00	19.35	70.00	21.21	80.00	22.95	55.00
O. reflexa	10.53	70.00	20.43	90.00	27.27	60.00	17.47	55.00
A. p. plicata	8.27	60.00	9.68	60.00	7.58	40.00	8.56	40.00
Q. nodulata	3.76	40.00	4.30	30.00	6.06	20.00	4.45	22.50
E. lineolata	5.26	50.00	4.30	30.00	1.52	10.00	4.11	22.50
Q. quadrula	3.01	30.00	2.15	10.00	1.52	10.00	2.40	12.50
C. tuberculata	2.26	20.00	1.08	10.00	1.52	10.00	1.71	10.00
U. imbecillis	2.26	20.00	1.08	10.00	1.52	10.00	1.71	10.00
E. crassidens	1.50	20.00	1.08	10.00	1.52	10.00	1.37	10.00
L. fragilis	0.00	0.00	4.30	20.00	0.00	0.00	1.37	5.00
Q. metanevra	2.26	30.00	1.08	10.00	0.00	0.00	1.37	10.00
T. donaciformis	0.75	10.00	0.00	0.00	1.52	10.00	0.68	5.00
P. alatus	0.00	0.00	1.08	10.00	0.00	0.00	0.34	2.50
T. verucosa	0.00	0.00	1.08	10.00	0.00	0.00	0.34	2.50
Total species	12		14		11		15	
Total individuals	153		93		66		292	
Total quadrats	10		10		10		40	
Total individuals <30 mm	14.28		12.9		25.76		16.44	
Total species <30 mm	33.33		35.71		45.45		46.67	
Menhinik's index	1.04		1.45		1.47		0.88	
Species diversity	1.9		2		1.84		1.96	
Equitability	0.7		0.75		0.78		0.69	
Mean density	57.2		40		30.8		42.9	
Standard error	7.59		8.5		4.31		4.52	

Table 16
Species Relative Abundance Based on Semiquantitative Sampling in the Lower Ohio River near Olmsted, August 1996

Species	No.	% Abundance
F. ebena	269	82.77
O. reflexa	11	3.38
Q. metanevra	8	2.46
A. p. plicata	7	2.15
Q. quadrula	6	1.85
E. lineolata	6	1.85
Q. pustulosa	5	1.54
M. nervosa	4	1.23
O. olivaria	3	0.92
E. crassidens	2	0.62
Q. nodulata	1	0.31
P. alatus	1	0.31
L. recta	1	0.31
P. cordatum	1	0.31
Total species	14	
Total individuals	325	
Total quadrats	36	
% Individuals <30 mm	5.85	
% Species <30 mm	21.42	
Menhinick's index	0.78	
Species diversity (H')	0.86	
Equitability	0.33	

qualitative Site 2. Heavy dominance of *F. ebena* was recorded once again; this species comprised 162 of 192 native mussels collected. Other species obtained at Site 2 were *Quadrula metanevra* (11), *Q. p. pustulosa* (6), *Obliquaria reflexa* (4), *Obovaria olivaria* (3), and one each of *Amblema p. plicata*, *Elliptio crassidens*, *Ellipsaria lineolata*, *Ligumia recta*, and *Lampsilis teres*.

To more fully evaluate uncommon species relative abundance, additional qualitative searches were conducted at qualitative Site 3 for all species except *F. ebena*. This search yielded 71 *Q. metanevra*, 20 *Q. p. pustulosa*, 8 *O. olivaria*, 8 *L. recta*, 8 *A. p. plicata*, 8 *Ellipsaria lineolata*, 6 *O. reflexa*, 5 *Q. quadrula*, 5 *E. crassidens*, 3 *Pleurobema cordatum*, 3 *Potamilus alatus*, and 3 *Q. nodulata*. Thus, excluding the heavily dominant *F. ebena*, a total of 13 other native mussel species were represented among 198 individuals of all subdominant taxa.

Quantitative sampling at three low-density sites in October yielded a total of 14 species and 137 individuals (Table 17). Approximately 18 percent of the community were comprised of recent recruits (mussels less than 30 mm long). Diversity was moderately low (1.47, Shannon Weaver index; 1.20 Menhinick's index). Equitability was moderate at 0.43 for all three sites. Dominance of *F. ebena* at these three sites was only moderate; the dominant species comprised 63 percent of the community at these locations. Species collected in October that were not collected in August included *Tritigonia verrucosa* and *Pyganodon grandis*. Only a single individual of each of these species was collected. It is not unusual for locally uncommon species not to be included in any particular sampling effort.

Table 17
Percent Species Abundance of Freshwater Mussels Collected in Quantitative Samples from the Lower Ohio River, August 1996

	Site Number					
Species	**1**	**2**	**3**	**4**	**5**	**Total**
F. ebena	100.00	70.00	0.00	30.00	100.00	60.00
Q. p. pustulosa	20.00	40.00	0.00	30.00	60.00	26.00
Q. nodulata	20.00	10.00	0.00	0.00	40.00	14.00
Q. metanevra	20.00	10.00	0.00	0.00	40.00	14.00
E. lineolata	0.00	10.00	0.00	0.00	50.00	12.00
Q. quadrula	0.00	30.00	0.00	0.00	0.00	6.00
A. p. plicata	20.00	0.00	0.00	0.00	20.00	8.00
Q. nodulata	10.00	0.00	0.00	10.00	10.00	6.00
M. nervosa	0.00	20.00	0.00	0.00	0.00	4.00
E. crassidens	10.00	0.00	0.00	0.00	10.00	4.00
O. olivaria	0.00	0.00	0.00	0.00	20.00	4.00
T. truncata	10.00	0.00	0.00	0.00	0.00	2.00
O. reflexa	0.00	0.00	0.00	0.00	10.00	2.00
T. donaciformis	10.00	0.00	0.00	0.00	0.00	2.00
Total quadrats	10	10	10	10	10	50

Post Creek. Because of reduced dominance of *F. ebena* at Post Creek (31 percent), species diversity and equitability are substantially higher than at Olmsted (Table 18). Density was moderate (29.2 individuals per square meter for all three sites combined). Diversity equaled 1.96 (Shannon-Weaver index) and 1.20 (Menhinick's index) for the three sites quantitatively sampled at Post Creek in October 1996. Equitability equaled 0.69. A total of 15 native unionid species were represented among 292 individuals. Recent recruits comprised 16 percent of the community; nearly half of all species obtained included at least one individuals less than 30 mm

Table 18
Species Relative Abundance and Frequency of Occurrence Based on Quantitative Samples of Freshwater Mussels in the Lower Ohio River near Olmsted, IL, October 1996

	Site Number							
	1		2		3		Total	
Species	Abun	Freq	Abun	Freq	Abun	Freq	Abun	Freq
F. ebena	60.42	100.00	65.31	90.00	62.50	80.00	62.77	90.00
Q. pustulosa	14.58	50.00	4.08	10.00	7.50	20.00	8.76	26.67
O. reflexa	4.17	20.00	6.12	20.00	5.00	20.00	5.11	20.00
Q. quadrula	4.17	20.00	6.12	30.00	5.00	20.00	5.11	23.33
E. lineolata	4.17	20.00	8.16	40.00	2.50	10.00	5.11	23.33
A. p. plicata	6.25	30.00	2.04	10.00	5.00	20.00	4.38	20.00
O. olivaria	2.08	10.00	4.08	20.00	5.00	10.00	3.65	13.33
T. verrucosa	0.00	0.00	2.04	10.00	0.00	0.00	0.73	3.33
Q. nodulata	0.00	0.00	2.04	10.00	0.00	0.00	0.73	3.33
C. tuberculata	2.08	10.00	0.00	0.00	0.00	0.00	0.73	3.33
T. donaciformis	0.00	0.00	0.00	0.00	2.50	10.00	0.73	3.33
P. alatus	0.00	0.00	0.00	0.00	2.50	10.00	0.73	3.33
P. grandis	2.08	10.00	0.00	0.00	0.00	0.00	0.73	3.33
Q. metanevra	0.00	0.00	0.00	0.00	2.50	10.00	0.73	3.33
Total species	9		9		10		14	
Total individuals	48		49		40		137	
Total quadrats	10		10		10		30	
% Individuals <30 mm	10.42		26.53		17.5		18.24	
% Species <30 mm	11.11		33.33		20		28.57	
Menhinick's index	1.30		1.29		1.60		1.20	
Species diversity (H')	1.40		1.32		1.46		1.47	
Equitability	0.53		0.47		0.47		0.43	
Mean density	19.20		20.00		18.80		19.60	
Standard error	1.10		2.52		3.35		2.45	

long. *Utterbackia imbecillis* was obtained at Post Creek but not Olmsted in 1996.

Size demography of native mussels. As generally indicated by the index of recent recruitment (mussels less than 30 mm long; Tables 14, 16, and 17), there was considerable evidence of recent recruitment of unionids to the Olmsted bed. Size demography analysis can be conducted in detail only for populations dense enough to yield a high number of individuals in quantitative samples. Among unionids at Olmsted, *F. ebena* is the only species of such abundance.

The size structure of the *F. ebena* population (Figure 21) showed a generally trimodal structure in August 1996, with a minor cohort of very recent recruits centered at approximately 12 mm (probably 1995 recruits), the very abundant 1990 year class centered at approximately 35 mm, and the once dominant 1981 cohort centered at approximately 70 mm. The maximum length of mussels collected in this population (off limits to legal commercial harvest) equaled 75 mm. The minimum length equaled 5 mm. This population is characterized by occasional very high recruitment (1981 and 1990 year classes), with some but relatively minor recruitment in most years.

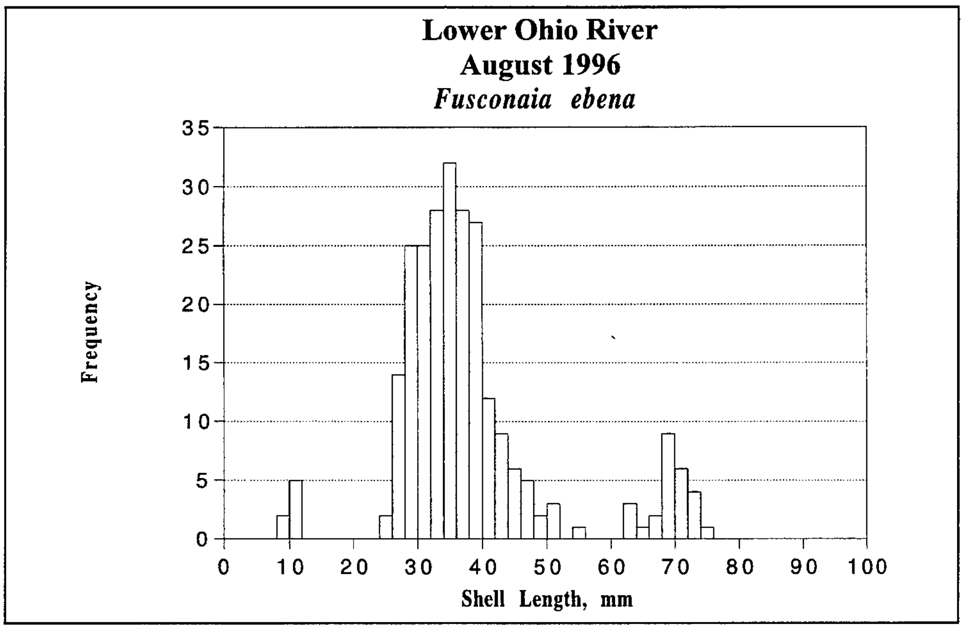


Figure 21. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River, August 1996

Although no other species of native mussels were collected in sufficient numbers to warrant detailed demographic analysis in August 1996, even with only a few individuals collected, other populations showed evidence of recent recruitment. For example, the most abundant *Q. p. pustulosa* were in the length range of 30 to 50 mm (Figure 22), a moderately small size likely to have been recruited at a time similar to the 1990 recruitment peak for *F. ebena*. A single individual less than 15 mm was among the 13 *Q. p. pustulosa* included in quantitative samples, indicating that some recruitment probably occurs in most years for this species. Similarly, a single *Q. metanevra* less than 15 mm long was included among just four individuals of that species collected in quantitative samples (Figure 23). Likewise, one of two *Q. nodulata* obtained was less than 15 mm long (Figure 24). No very small *Q. quadrula* were found (Figure 25).

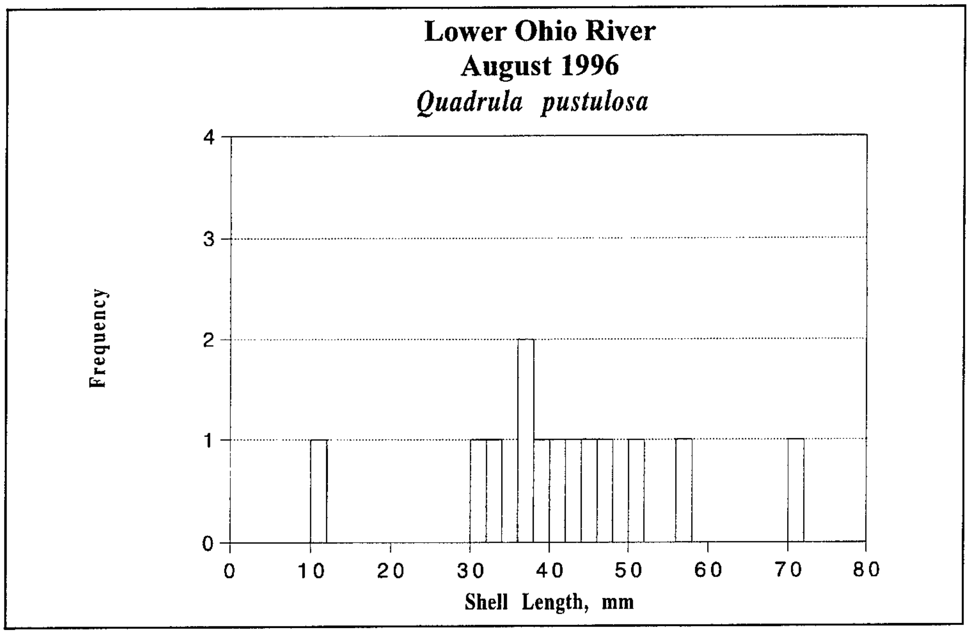


Figure 22. Length frequency histogram for *Quadrula p. pustulosa*, Lower Ohio River, August 1996

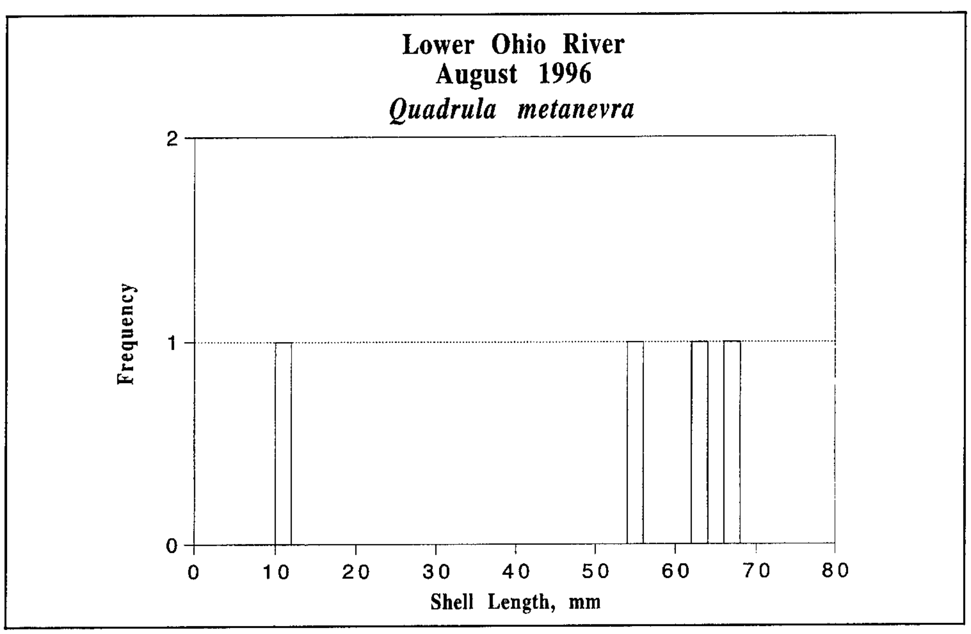


Figure 23. Length frequency historgram for *Quadrula metanevra*, Lower Ohio River, August 1996

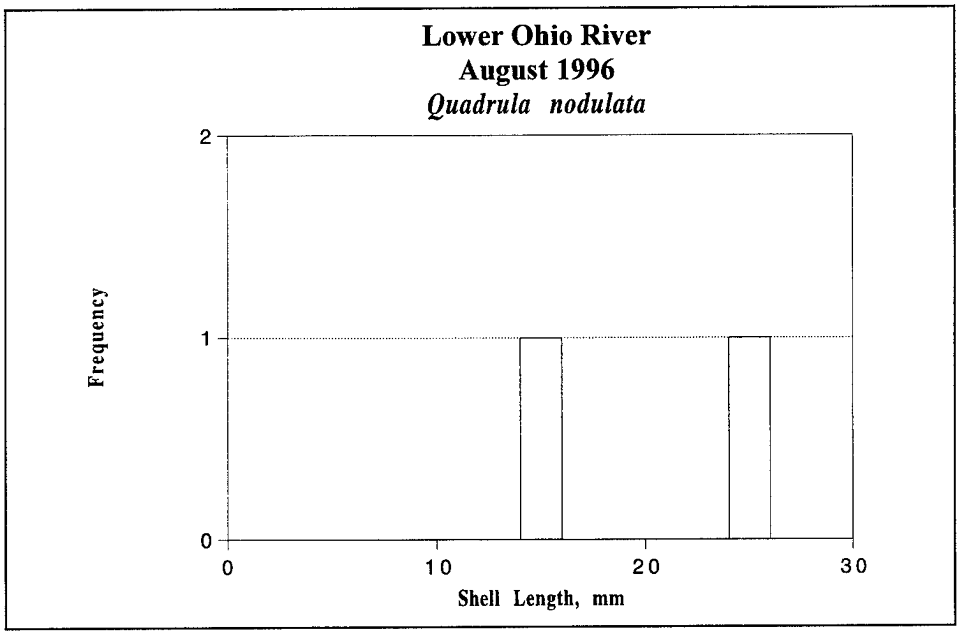


Figure 24. Length frequency histogram for *Quadrula nodulata*, Lower Ohio River, August 1996

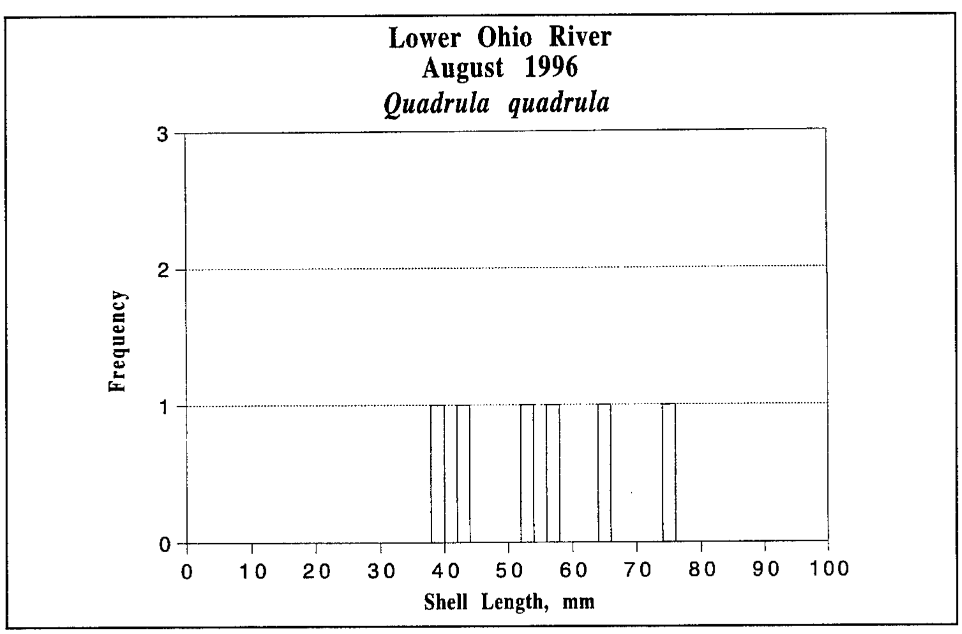


Figure 25. Length frequency histogram for *Quadrula quadrula*, Lower Ohio River, August 1996

Intersite differences were apparent in the size structure of the dominant *F. ebena* population (Figures 26-28). The average length of the dominant 1990 cohort in August 1996 was greater at Sites 3, 4, and 5 (approximately 39 mm) than at Site 1 (approximately 32 mm). Site 2 was different from the other sites in that the 1990 cohort was dominant at that location. It is noteworthy that Site 2 was at an elevation of 265 ft and thus possible slightly farshore of the general limit of the mussel bed.

In October 1996, the *Fusconaia ebena* population looked similar in size structure as it did in August (Figure 29). The minor cohort of recent recruits had grown to an average length of approximately 15 mm. The 1990 year class heavily dominated the population and had an average length of 37 mm. Hardly any individuals of the 1981 year class were obtained in the October sample, almost certainly due to a moderately small sample size rather than lack of individuals of the 1981 year class.

Size structure of other subdominant populations in October is shown in Figures 30 through 32. Despite a low number of individuals per sample, it was evident that *Quadrula pustulosa*, *Obliquaria reflexa*, and *Ellipsaria lineolata* populations were, like *F. ebena*, all dominated by moderate-sized individuals rather than very recent recruits or old, large mussels.

Intersite differences in size structure of the *F. ebena* population were not evident in October 1996 (Figures 33 and 34). Recall that sites in October 1996 were in very close proximity. All three sites were heavily dominated by the 1990 cohort, which had average length of approximately 36 mm at all locations.

Nonindigenous species. Density of the Asian clam, *Corbicula fluminea*, at Olmsted in August 1996 was very low, averaging only 0.3 individuals per square meter. Not surprisingly, density was low again in October, averaging 0.9 individuals per square meter. The simplicity of population size structure was evident by the fact that no individuals greater than 15 mm long were obtained in quantitative samples in August (Figure 35). In October, no individuals greater than 17 mm long were collected (Figure 36).

Dreissena polymorpha were moderately dense at Olmsted in August 1996, with the population being comprised of two cohorts (Figure 37). The more abundant cohort had an average length of approximately 3 mm and ranged from 1 to 7 mm. These individuals almost certainly represented 1996 recruitment. The second cohort, with average length of 13 mm and range of 10 to 17 mm, represented the 1995 generation. Thus, it appears that *D. polymorpha* in the lower Ohio River has a lifespan of just more than 1 year, with individuals dying shortly after they reproduce at age one. By October, the 1995 cohort had died, and the 1996 cohort had grown to an average length of approximately 10 mm. *Dreissena* density in October was slightly less than 1,000 individuals per square meter.

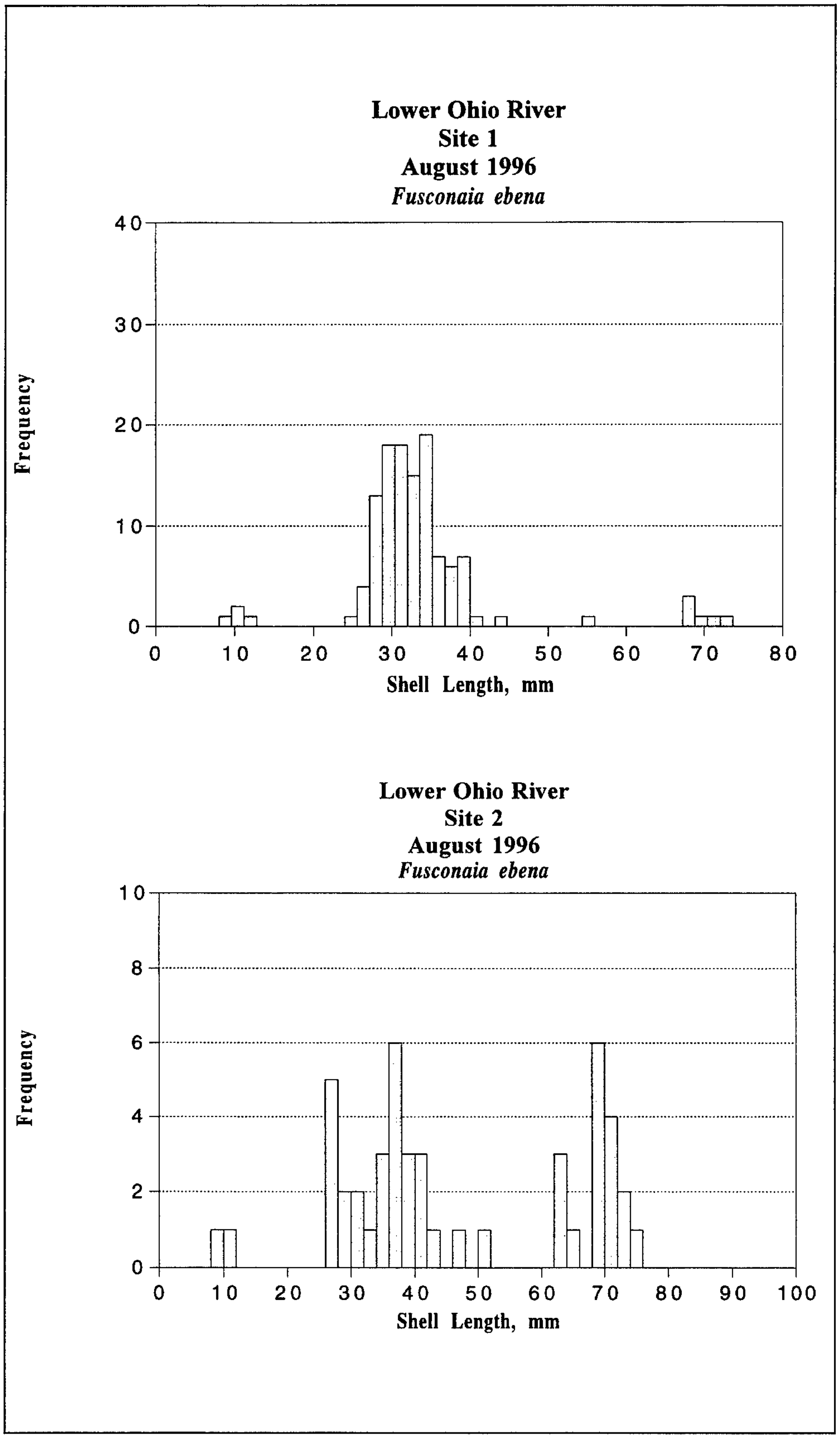


Figure 26. Length frequency histograms for *Fusconaia ebena* at Sites 1 and 2, Lower Ohio River, August 1996

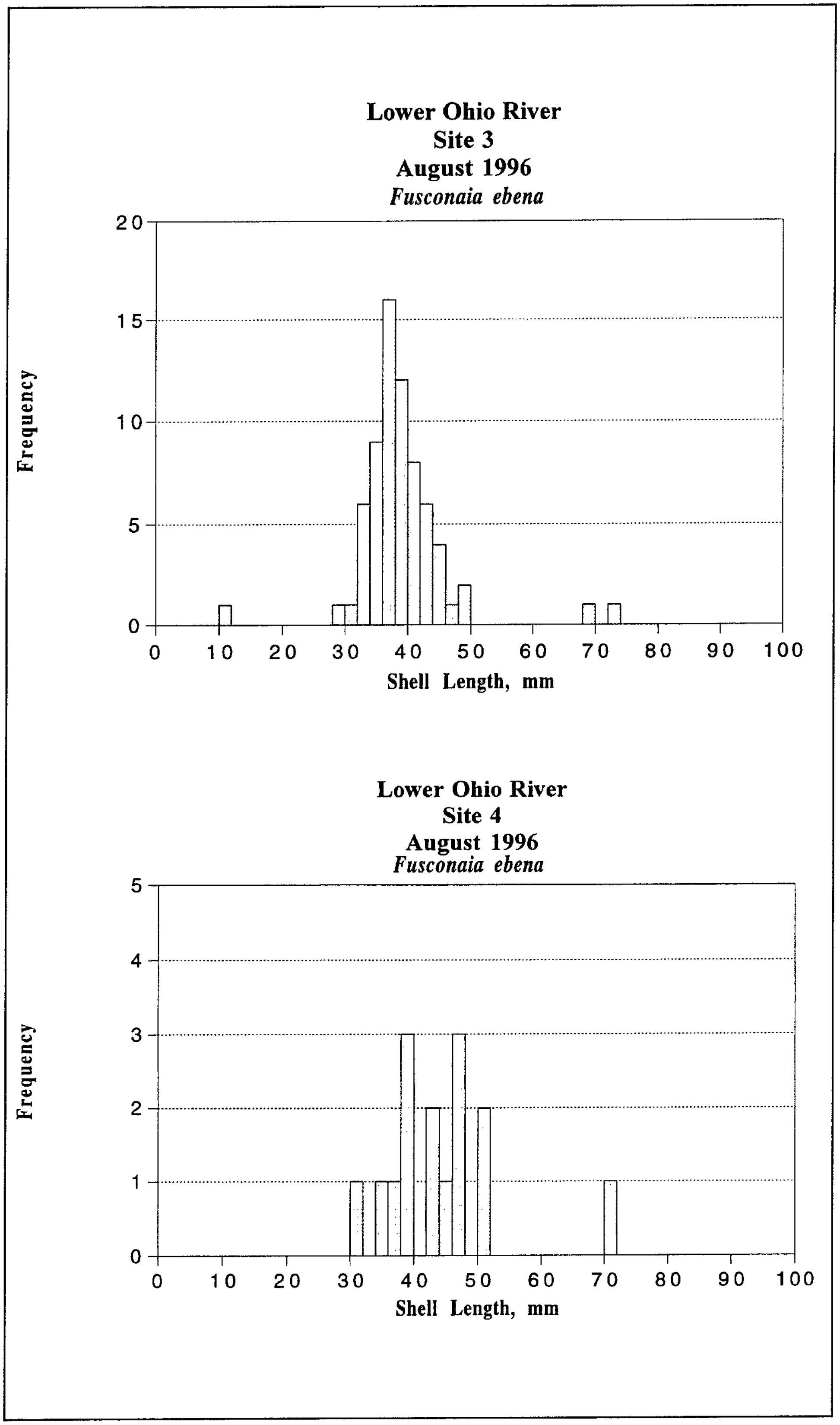


Figure 27. Length frequency histograms for *Fusconaia ebena* at Sites 3 and 4, Lower Ohio River, August 1996

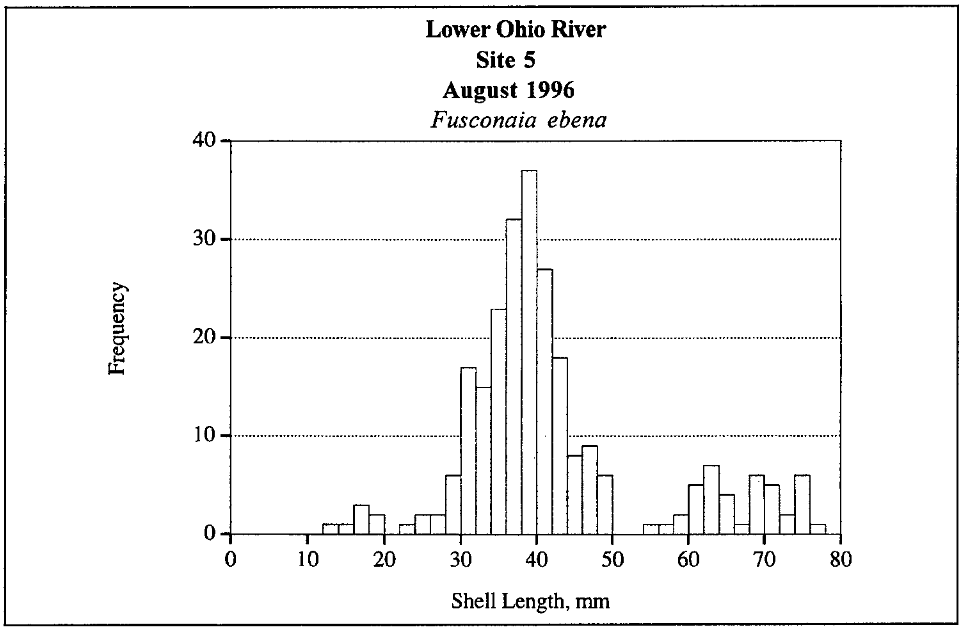


Figure 28. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River, August 1996

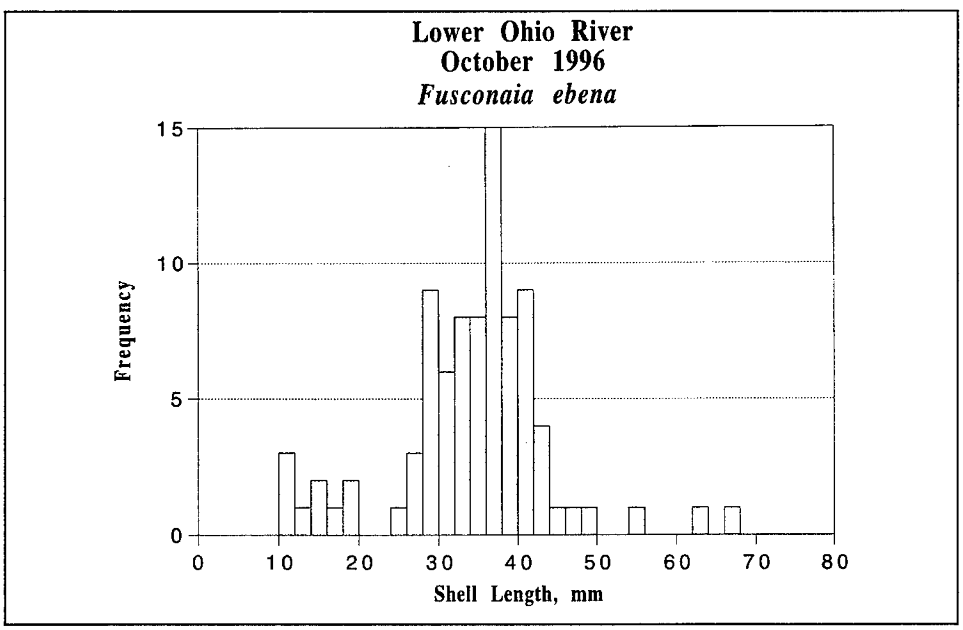


Figure 29. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River, October 1996

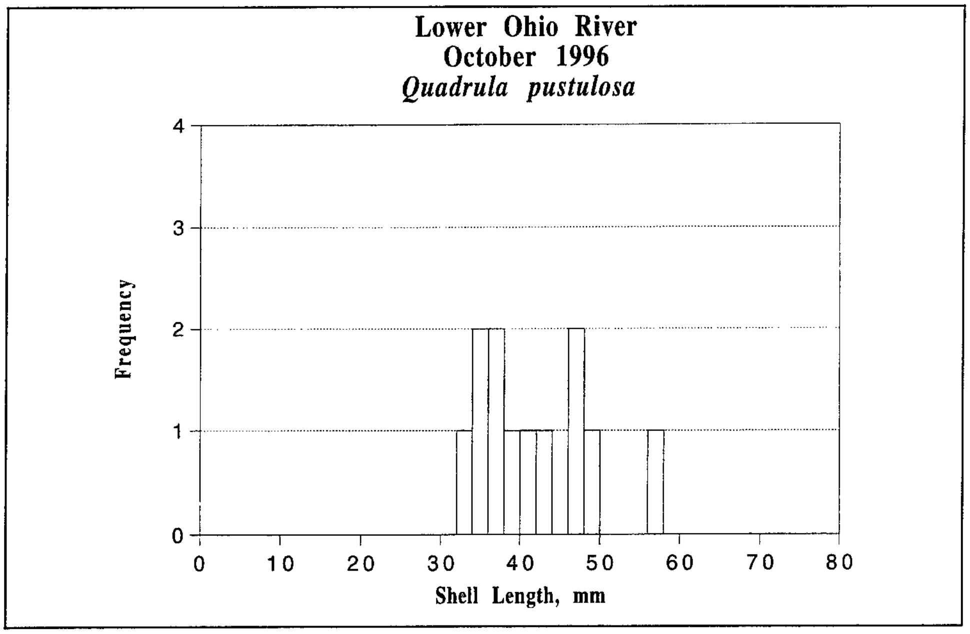


Figure 30. Length frequency histogram for *Quadrula p. pustulosa*, Lower Ohio River, October 1996

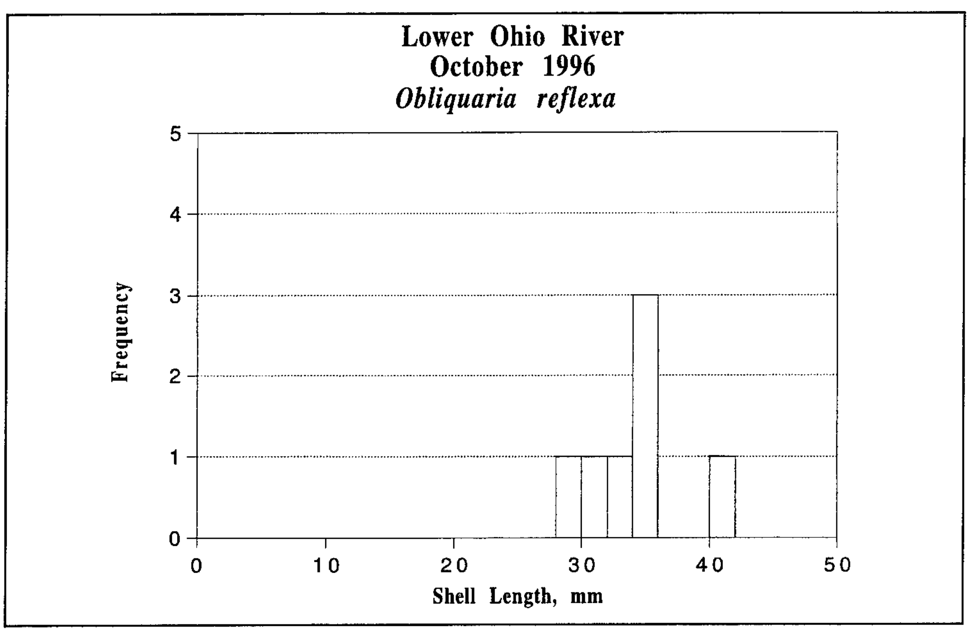


Figure 31. Length frequency histogram for *Obliquaria reflexa*, Lower Ohio River, October 1996

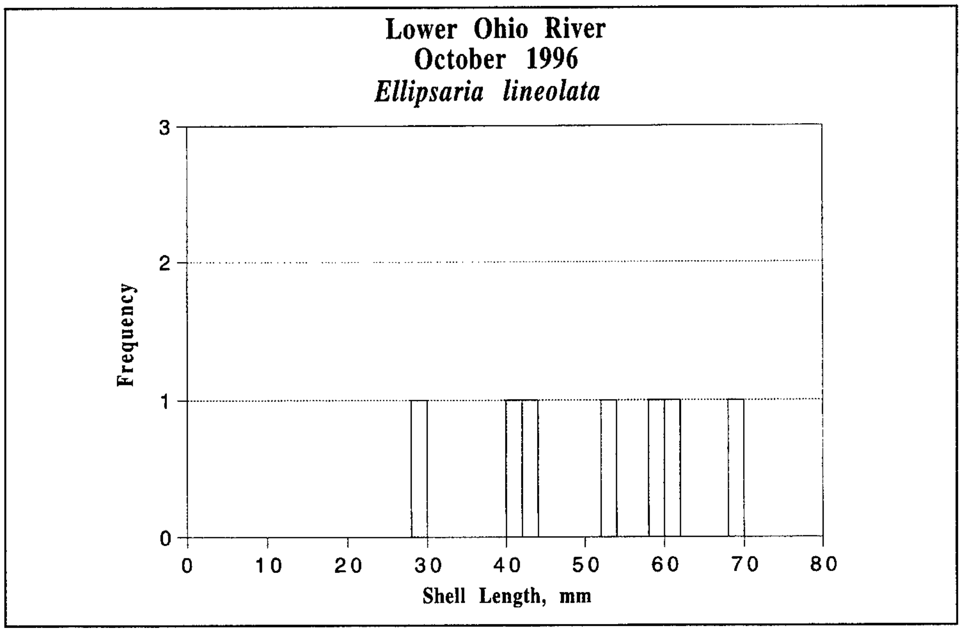


Figure 32. Length frequency histogram for *Ellipsaria lineolata*, Lower Ohio River, October 1996

Native mussels collected semiquantitatively at Olmsted in August mostly (81 percent) were not infested at all by live *Dreissena polymorpha*, although 9 percent of native mussels were heavily infested (Table 13). A total of 325 unionids were collected semiquantitatively. No infestation by live zebra mussels characterized 264 of these 325 individuals. Twelve unionids had 1-10 attached zebra mussels. Twenty-one unionids had 10-50 attached zebra mussels. Twenty-eight unionids had greater than 50 zebra mussels attached to their shells. However, most unionids, including those without live zebra mussels attached, had byssal tufts attached to their shells. These tufts are indicative of previous infestation by now dead or translocated zebra mussels.

The zebra mussel population at Post Creek in October was comprised of two cohorts (Figures 38 and 39). The most abundant cohort, accounting for approximately 75 percent of the population, ranged mostly from 7 to 12 mm in length and had average length of approximately 9 mm. This cohort probably represented 1996 recruitment. The remaining cohort ranged in length from 13 to 20 mm and had average length of 16 mm. This cohort of larger, older mussels probably represented 1995 recruitment.

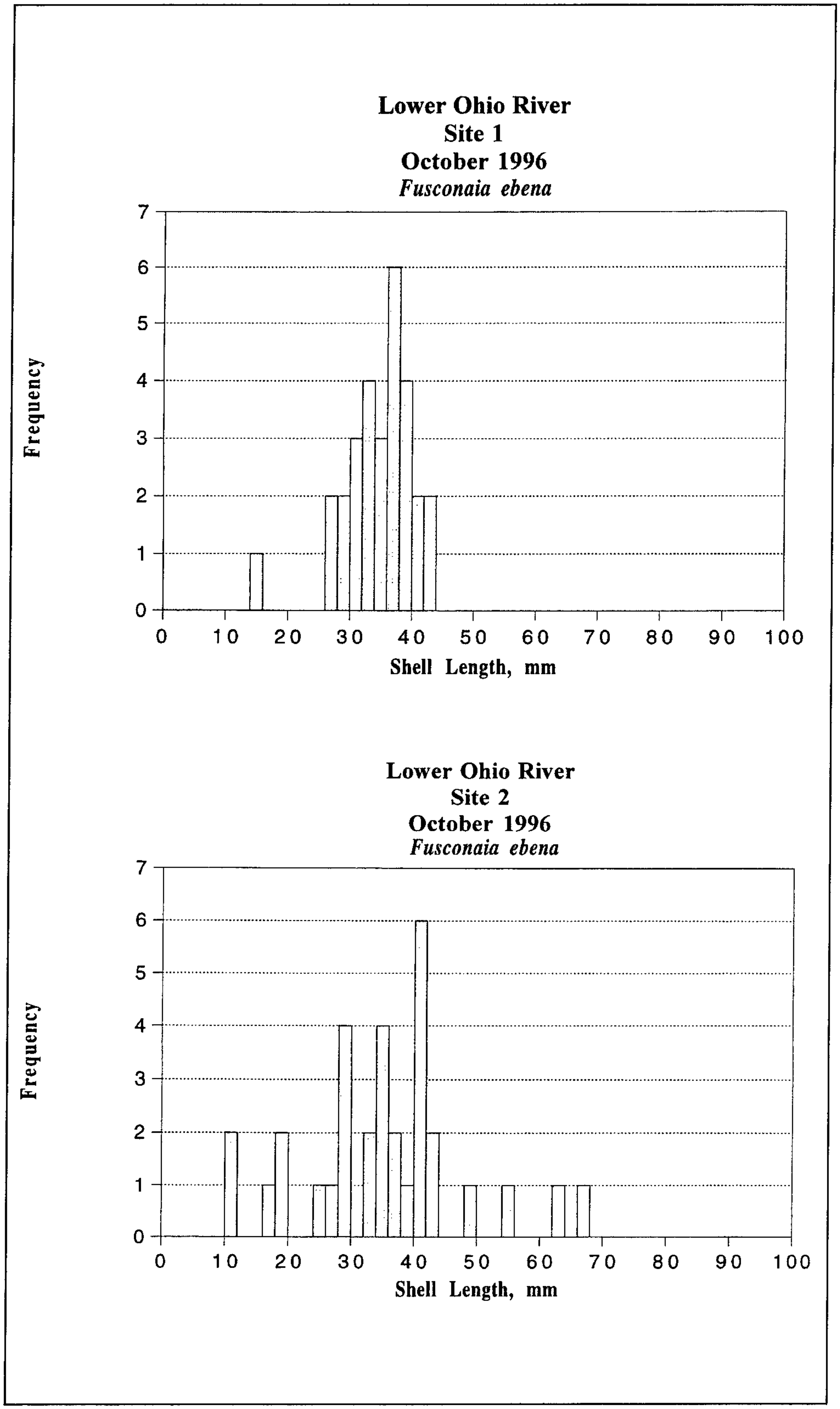


Figure 33. Length frequency histograms for *Fusconaia ebena* at Sites 1 and 2, Lower Ohio River, October 1996

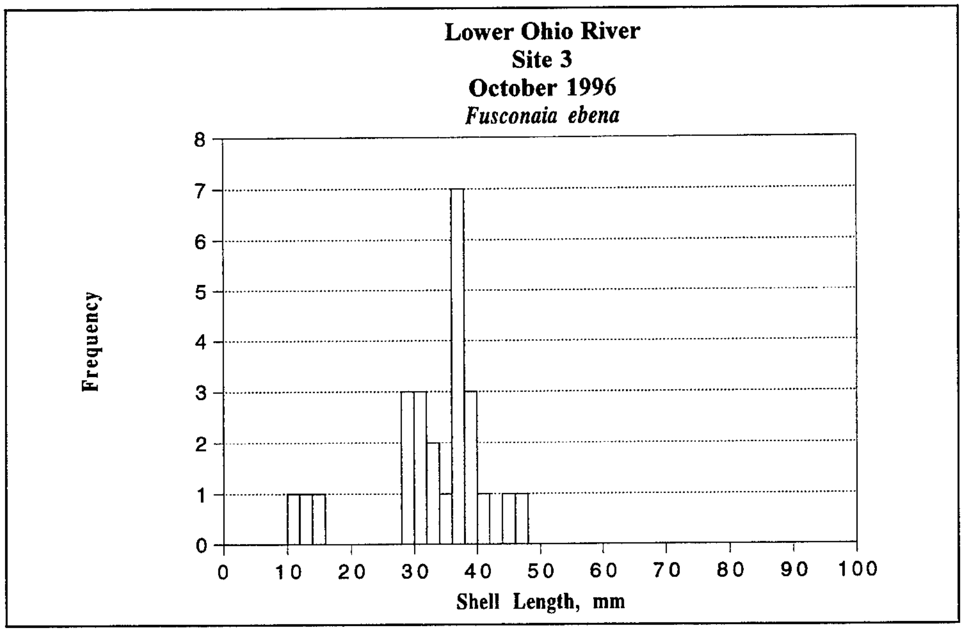


Figure 34. Length frequency histogram for *Fusconaia ebena* at Site 3, Lower Ohio River, October 1996

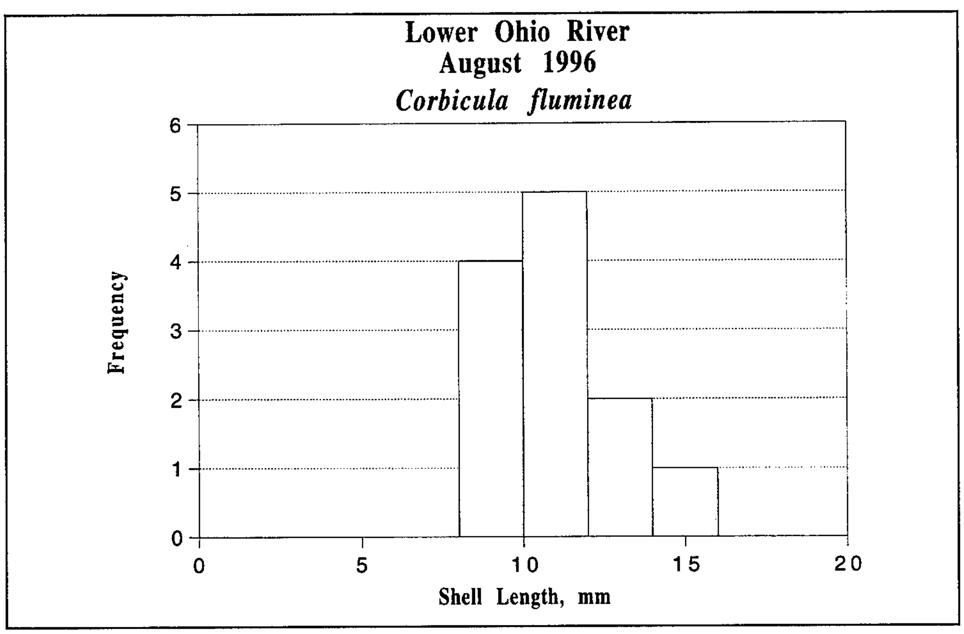


Figure 35. Length frequency histogram for *Corbicula fluminea*, Lower Ohio River, August 1996

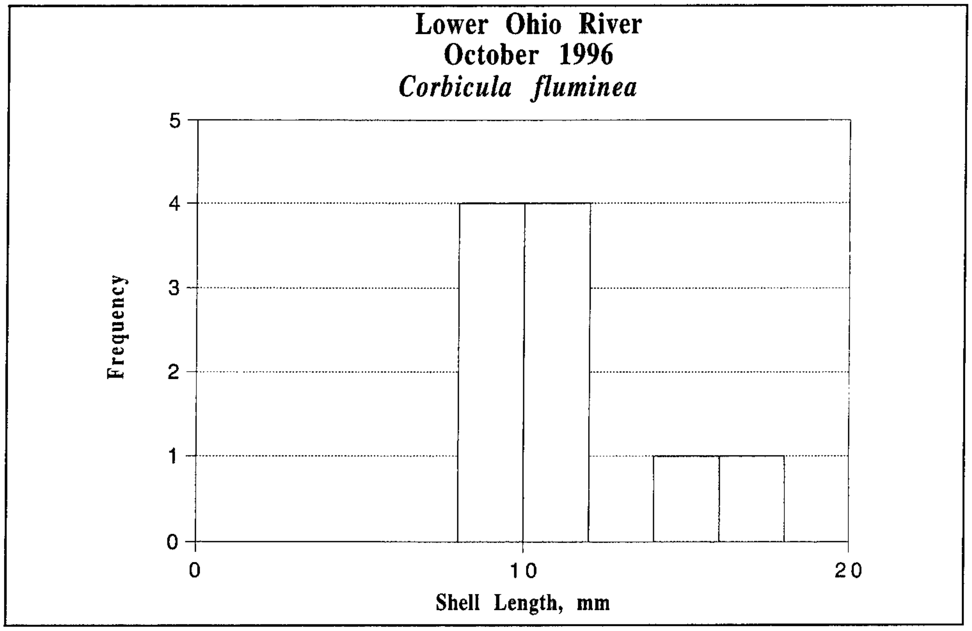


Figure 36. Length frequency histogram for *Corbicula fluminea*, Lower Ohio River, October 1996

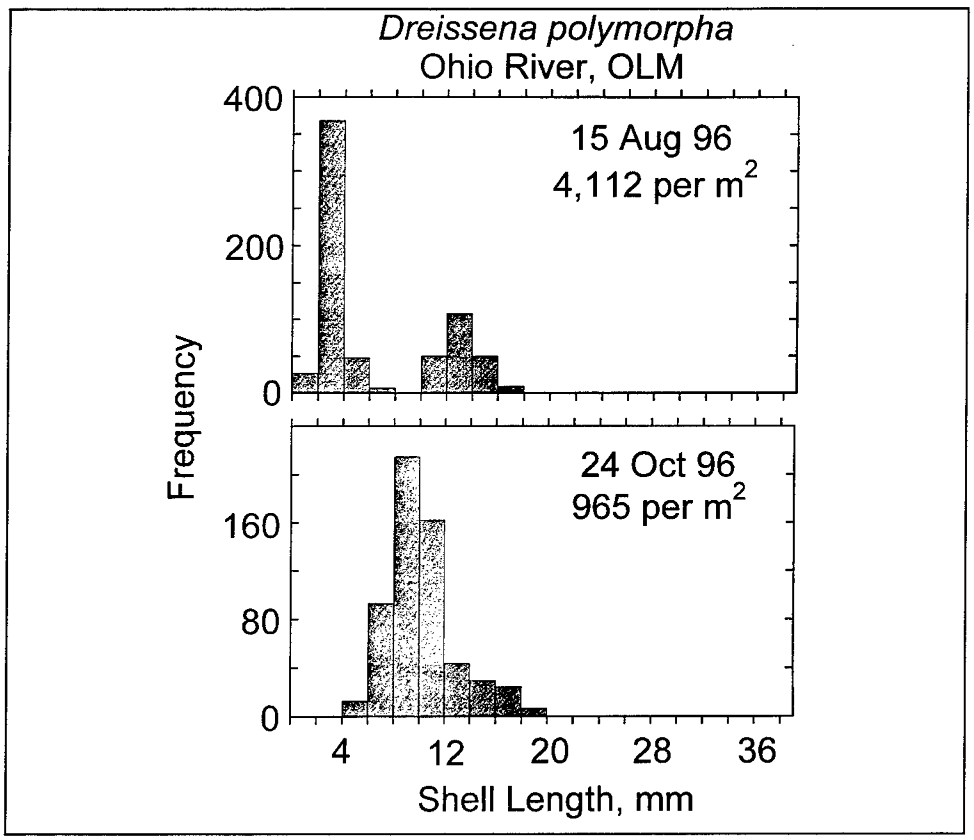


Figure 37. Length frequency histograms for the zebra mussel, *Dreissena polymorpha*, Lower Ohio River, August 1996 and October 1996

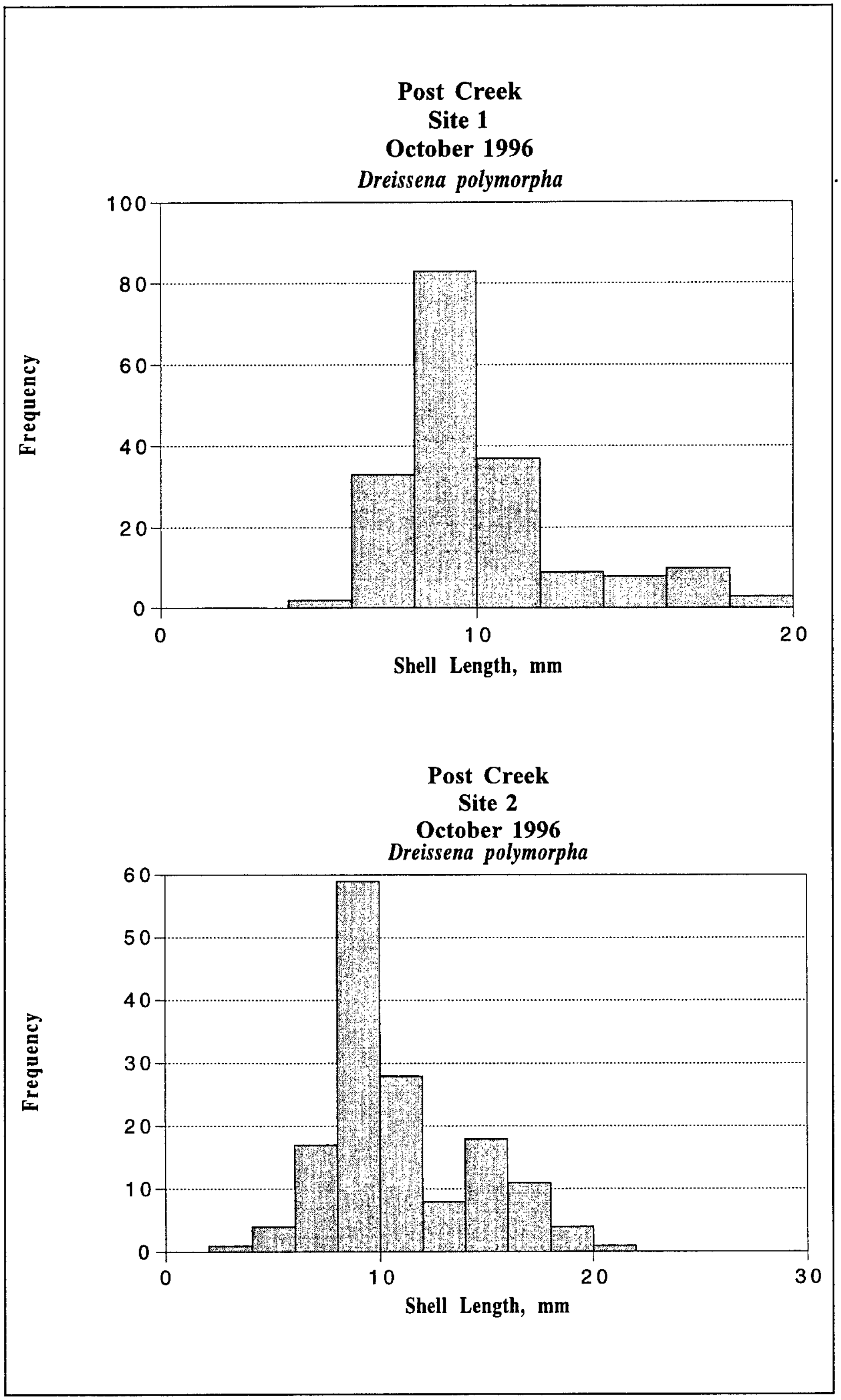


Figure 38. Length frequency histograms for the zebra mussel, *Dreissena polymorpha*, at Sites 1 and 2, Lower Ohio River near Post Creek, October 1996

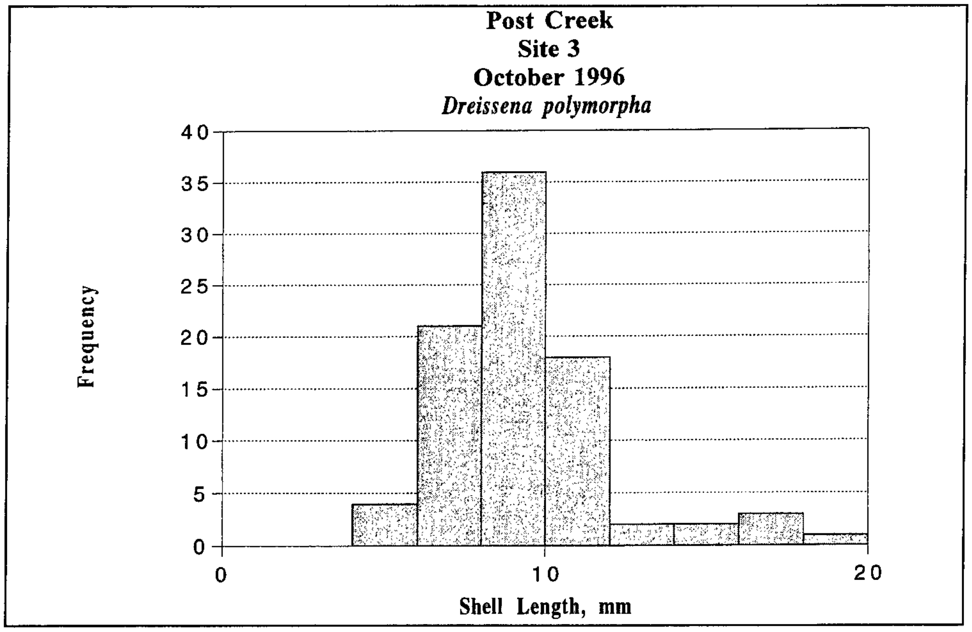


Figure 39. Length frequency histogram for the zebra mussel, *Dreissena polymorpha*, at Site 3, Lower Ohio River near Post Creek, October 1996

4 1997 Studies

Sites and Methods

Studies were conducted at both the Olmsted and Post Creek locations between 8 and 11 August 1997 and at Olmsted and Four Mile Creek on 16 September 1997.

August studies included an extensive series of semiquantitative samples (30 sites with four samples per site) to describe spatial variation in mussel density in relation to elevation and substratum (Table 19). Zebra mussel density was also evaluated at these locations. In addition, three sets of 10 quantitative samples of substratum with mussels were collected near the center of the bed (Table 20), adding to long-term monitoring data on density, size demography of dominant populations, recruitment, and community composition of this historically and ecologically prominent mussel bed. August sampling included a similar set of quantitative substratum and mussel samples from the Post Creek location, an area of special interest because of pool elevation increase that will occur after completion of the Olmsted Locks and Dam Project.

September sampling consisted of qualitative searches for pustulose shells at the Olmsted bed to check for occurrence of *Plethobasus cooperianus*. In addition, quantitative samples were taken of the pleurocerid snail community, of special interest because they are recovering from massive mortality associated with the tremendous recruitment of zebra mussels to this area in 1993 (Payne and Miller 1997). Sampling at the Four Mile Creek location in September included qualitative searches for unionids to describe community composition and species richness.

Table 19
Locations and Elevations of August 1997 Semiquantitative Samples from a Mussel Bed in the Lower Ohio River near Olmsted, IL

Latitude (degrees North)	Longitude (degrees West)	Samples	Elevation (feet above mean sea level)
3709.451	8905.536	4-1 near (n = 4) 4-2 far (n = 4)	263 263
3709.405	8905.450	4-3 near (n = 4) 4-4 far (n = 4)	280 273
3709.291	8905.638	5-1 near (n = 4) 5-2 far (n = 4)	280 274
3709.211	8905.620	5-3 near (n = 4) 5-4 far (n = 4)	274 268
3709.139	8905.667	6-1 near (n = 4) 6-2 far (n = 4)	276 272
3709.040	8905.738	6-3 near (n = 4) 6-4 far (n = 4)	277 277
3709.032	8905.683	6-5 near (n = 4) 6-6 far (n = 4)	273 271
3708.986	8905.750	7-1 near (n = 4) 7-2 far (n = 4)	276 275
3708.844	8905.780	7-3 near (n = 4) 7-4 far (n = 4)	277 274
3708.895	8905.721	7-5 near (n = 4) 7-6 far (n = 4)	275 270
3708.772	8905.736	8-1 near (n = 4) 8-2 far (n = 4)	271 271
3708.766	8905.785	8-3 near (n = 4) 8-4 far (n = 4)	275 269
3708.803	8905.750	8-5 near (n = 4) 8-6 (n = 4)	272 267
3708.668	8905.869	9-1 far (n = 4) 9-2 near (n = 4)	277 280
3708.562	8905.906	9-3 near (n = 4) 9-4 far (n = 4)	277 276

Table 20
Locations and Elevations of August 1997 Quantitative Samples from a Mussel Bed in the Lower Ohio River near Olmsted, IL

Latitude (degrees North)	Longitude (degrees West)	Samples	Elevation (feet above mean sea level)	River Mile
3708.830	8905.786	Site 1 (n = 10)	276	967.5
3708.821	8905.811	Site 2 (n = 10)	277	967.6
3708.975	8905.710	Site 3 (n = 10)	274	967.3

Results

Spatial distribution of mussels at Olmsted

Semiquantitative samples ranged from elevation 263 to 280 (Table 21). The edges of the mussel bed generally correspond to the 267- and 279-ft contours. Unionid density ranged from an average of 0 (Sites 4-3 and 8-3) to 258 (Site 8-5) mussels per square meter at a particular site. Site 4-3 with no mussels was at elevation 280, and thus just nearshore of the general limit of the bed. However, Site 8-3 with no mussels was at elevation 275, clearly within the general boundaries of the mussel bed. Similarly, Sites 7-5 and 7-6, with average density of 111 and 11 individuals per square meter, were both within the general limits of the bed at elevations of 275 and 270 ft. Furthermore, these two sites were separated by a distance of only approximately 200 ft. The occurrence of some zero density sites and of closely adjacent sites with greatly different average density, all within the mussel bed, is a manifestation of spatial patchiness in mussel density. Most sites showed moderately high interquadrat variability, with variance to mean ratios generally exceeding unity (Table 21). At some sites (e.g., Site 7-4), such variance was striking.

Mean density estimates from four rather than two semiquantitative samples per site allowed more accurate estimation of mean density. Thus, a plot of site averages of density versus elevation clearly supports that the 267- and 279-ft elevation contours correspond to the farshore and nearshore limits of the mussel bed (Figure 40). However, great variation in mussel density existed within these bounds. Between elevations 267 and 279, eight sites had fewer than 20 individuals per square meter (low density). These sites were at elevations 267, 270, 271, 273, 274 (two sites), 275, and 277, and thus were scattered across the width of the mussel bed. Ten sites had from 20 to 50 individuals per square meter (moderate density). These sites occurred at elevations 268, 269, 271, 275, 276 (three sites), 277 (three sites), perhaps indicating a tendency toward higher (generally more nearshore) elevations within the bed. Seven sites supported more than 50 individuals per square meter (high density). These sites

Table 21
Density and Substratum Conditions Based on August 1997 Semiquantitative Samples from a Mussel Bed in the Lower Ohio River near Olmsted, IL

Site	Mussels per Quadrat	Mussels per m^2 Mean (SD)	Substratum Class	Elevation feet above MSL
4-1	1, 0, 0, 0	1.0 (2.0)	5	263
4-2	0, 1, 0, 0	1.0 (2.0)	5	263
4-3	0, 0, 0, 0	0.0 (0.0)	2.5	280
4-4	3, 6, 4, 2	15.0 (6.8)	2	273
5-1	0, 0, 1, 1	2.0 (2.3)	4	280
5-2	2, 0, 3, 2	7.0 (5.0)	2	274
5-3	3, 6, 2, 4	15.0 (6.8)	3	274
5-4	5, 7, 5, 14	31.0 (17.1)	2.5	268
6-1	7, 6, 2, 12	27.0 (16.5)	2.5	276
6-2	36, 31, 23, 40	130.0 (29.3)	4	272
6-3	2, 5, 7, 14	28.0 (20.4)	2.5	277
6-4	9, 13, 1, 5	28.0 (20.7)	3	277
6-5	18, 20, nd, nd	76.0 (5.7)	2	273
6-6	14, 19, nd, nd	66.0 (14.1)	2	271
7-1	7, 1, 13, 9	30.0 (20.0)	3	276
7-2	8, 9, 13, 8	38.0 (9.5)	3	275
7-3	19, 13, 13, 9	34.0 (16.5)	2.5	277
7-4	1, 29, 19, 38	87.0 (63.5)	4	274
7-5	9, 46, 24, 32	111.0 (61.8)	4	275
7-6	3, 4, 1, 3	11.0 (5.0)	2	270
8-1	2, 2, 2, 3	9.0 (2.0)	4	271
8-2	5, 6, 4, 5	20.0 (3.3)	4	271
8-3	0, 0, 0, 0	0.0 (0.0)	3	275
8-4	8, 5, 5, 8	26.0 (6.9)	3	269
8-5	55, 64, 48, 90	258.0 (72.9)	2.5	272
8-6	0, 2, 0, 0	2.0 (4.0)	3	267
9-1	8, 6, 5, 0	2.0 (4.0)	2	277
9-2	3, 2, 3, 2	10.0 (2.3)	3	280
9-3	5, 7, 10, 5	27.0 (9.5)	2.5	277
9-4	14, 5, 3, 9	31.0 (19.4)	3	276

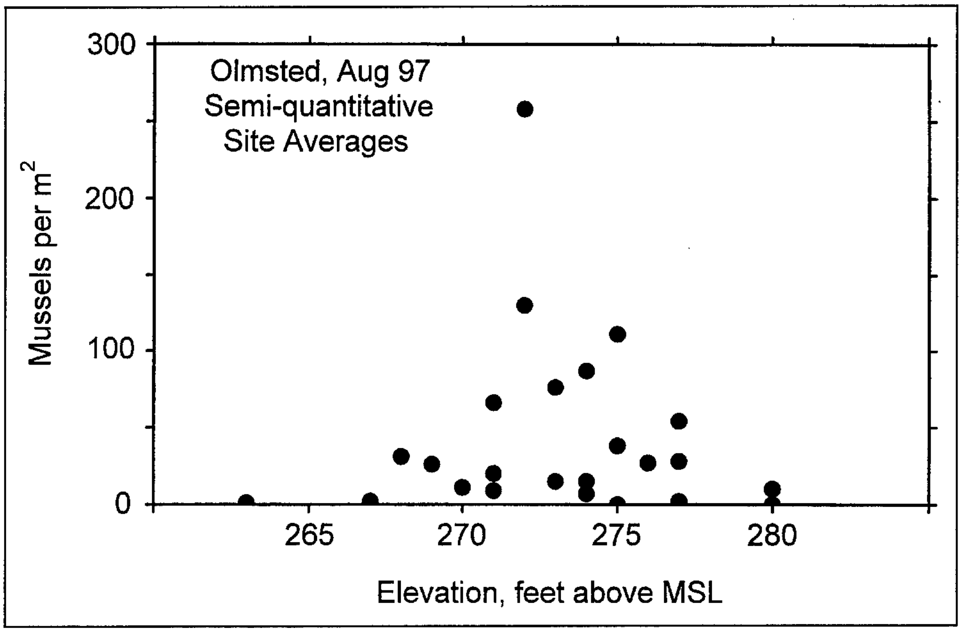


Figure 40. Native mussel density in relation to elevation, Lower Ohio River, August 1997

occurred at elevations 271, 272 (two sites), 273, 274, 275, and 277, mostly central elevations of the bed.

Unionid density is shown in relation to substratum type in Figure 41. No discernable pattern is evident in these data.

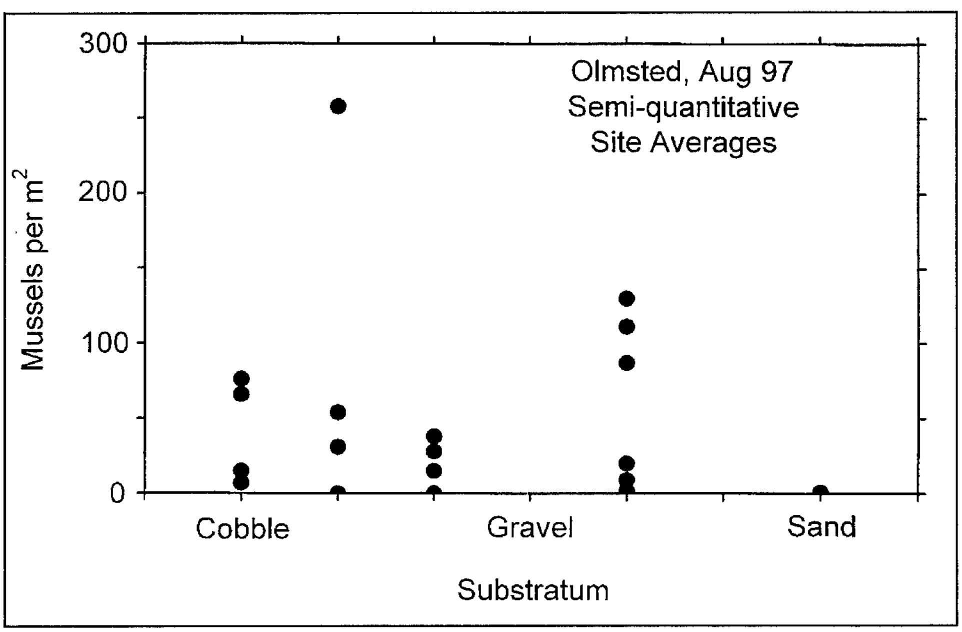


Figure 41. Native mussel density in relation to predominant substratum type, Lower Ohio River, August 1997

Mussel density at quantitative sites (n =10 0.025-m^2 quadrats per site) in August 1997 averaged (SD) 57.2 (18.9), 53.6(10.0), and 10.4 (7.1) individuals per square meter at Sites 1, 2, and 3, respectively (Table 22). Thus, the first two sites were from locations of high mussel density, and the third site was from an area of moderately low density. All three sites were within the nearshore and farshore limits of the bed, occurring at elevations of 274 to 277 ft. Furthermore, the three sites were within a 0.2-mile reach (from RM 967.3 to 967.5) near the center of the bed. Thus, as with semiquantitative results, quantitative sampling indicated considerable intersite variation in mussel density within the bed. Even at the spatial scale of interquadrat variation within sites, patchiness of mussel density was evident. Variance-to-mean ratios of density, indicative of aggregation if greater than unity, equaled 6.2, 1.9, and 4.9 at Sites 1, 2, and 3, respectively.

Table 22
Density of Native and Nonindigenous Bivalves Based on Quantitative Sampling at the Olmsted and Post Creek Locations in the Lower Ohio River, August 1997

	Site 1		Site 2		Site 3		All Sites	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Olmsted Mussel Bed								
D. polymorpha	400.8	393.3	184.0	84.1	0.0	0.0	195.2	279.2
C. fluminea	1.6	2.1	1.2	1.9	0.8	1.7	1.2	1.9
Native mussels	57.2	18.9	53.6	10.0	10.4	7.1	40.4	25.0
Post Creek Mussel Bed								
D. polymorpha	7.2	10.5	81.6	48.8	214.0	118.1	100.9	112.6
C. fluminea	7.6	7.4	2.4	3.9	1.6	2.1	3.9	5.5
Native mussels	24.0	19.5	54.4	19.1	36.0	13.5	38.1	21.2

Native mussel community composition

Olmsted. *Fusconaia ebena* was heavily dominant at all three quantitative sites sampled at Olmsted in August 1997 (Tables 23 and 24. Relative abundance of *F. ebena* ranged from 76.9 percent at Site 3 to 78.4 percent at Site 2. A total of 15 species and 303 individuals were collected by quantitative methods at all sites. Species collected other than *F. ebena* included *Q. pustulosa* (5.3 percent), *E. lineolata* (4.3 percent), *O. reflexa* (2.3 percent), *Q. metanevra* (2.0 percent), *A. p. plicata* (1.7 percent), and *T. donaciformis* (1.7 percent). Eight species individually comprised less than 1 percent of the fauna: *Q. quadrula*, *E. crassidens*, *P. alatus*, *Q. nodulata*, *O. olivaria*, *P. cordatum*, *L. recta*, and *T. truncata*. Species diversity was low, measuring 1.01 (Shannon-Weaver index) and 0.86 (Menhinick's index) for the combined samples from all quantitative sites. Evenness, at 0.35, was also low. Recent recruitment evidence was moderate; approximately 14 percent of all individuals collected were less than 30 mm long.

Table 23
Percent Abundance of Unionid Species Collected at Three Subsites in the Lower Ohio River, Mile 967, August 1997

Species	Subsite 1	Subsite 2	Subsite 3	Total
F. ebena	78.32	78.36	76.92	78.22
Q. pustulosa	4.90	6.72	0.00	5.28
E. lineolata	5.59	2.99	3.85	4.29
O. reflexa	2.80	2.24	0.00	2.31
Q. metanevra	0.70	2.24	7.69	1.98
A. p. plicata	1.40	1.49	3.85	1.65
T. donaciformis	0.70	2.99	0.00	1.65
Q. quadrula	2.10	0.00	0.00	0.99
E. crassidens	0.00	1.49	0.00	0.66
P. alatus	0.70	0.75	0.00	0.66
Q. nodulata	0.70	0.00	3.85	0.66
O. olivaria	0.70	0.75	0.00	0.66
P. cordatum	0.70	0.00	0.00	0.33
L. recta	0.00	0.00	3.85	0.33
T. truncata	0.70	0.00	0.00	0.33
Total individuals	143	134	26	303
Total species	13	10	6	15
Menhinick's index	1.09	0.86	1.18	0.86
Species diversity	0.98	0.95	0.9	1.01
Evenness	0.37	0.39	0.48	0.35
% Individuals <30 mm	13.29	15.67	7.69	13.86
% Species <30 mm	53.84	40	33.33	53.33

Table 24
Percent Occurrence of Unionid Species Collected at Three Subsites in the Lower Ohio River, Mile 967, August 1997

Species	Subsite 1	Subsite 2	Subsite 3	Total
F. ebena	100.0	100.0	80.0	93.3
Q. pustulosa	50.0	80.0	0.0	43.3
E. lineolata	40.0	40.0	10.0	30.0
O. reflexa	30.0	30.0	0.0	20.0
Q. metanevra	10.0	30.0	20.0	20.0
A. p. plicata	20.0	20.0	10.0	16.7
T. donaciformis	10.0	40.0	0.0	16.7
Q. quadrula	20.0	0.0	0.0	6.7
E. crassidens	0.0	20.0	0.0	6.7
P. alatus	10.0	10.0	0.0	6.7
Q. nodulata	10.0	0.0	10.0	6.7
O. olivaria	10.0	10.0	0.0	6.7
P. cordatum	10.0	0.0	0.0	3.3
L. recta	0.0	0.0	10.0	3.3
T. truncata	10.0	0.0	0.0	3.3
Total sites	10	10	10	30

In addition, recruitment appeared to be a community phenomenon rather than specific to just *F. ebena*. Fifty-three percent of all species included at least one individual less than 30 mm long.

Qualitative sampling at two sites at Olmsted in September 1997 yielded a total of 172 native unionids and 12 species. These sites were located at 3708.880 N, 8905.829 W (elevation 278) and 3708.856 N, 8905.779 W (elevation 274). The community was heavily dominated by *Fusconaia ebena* (n = 175). Other species collected were, in order of abundance, *Quadrula metanevra* (9), *Obliquaria reflexa* (7), *Ellipsaria lineolata* (6), *Q. pustulosa* (5), *Q. quadrula* (4), *A. plicata* (3), *Obovaria olivaria* (3), *Ligumia recta* (2), *Q. nodulata* (1), *E. crassidens* (1), and *C. tuberculata* (1). An additional 20-min search by two divers for pustulose shells did not yield any *Plethobasus cooperianus*, although two *P. cyphyus* were added to the list of species above.

Post Creek. Unionid density was moderately high, averaging 24.0, 54.4, and 36.0 individuals per square meter at Sites 1, 2, and 3, respectively, quantitatively sampled at Post Creek in August 1997 (Table 22). *Fusconaia ebena* was slightly less dominant at Post Creek (66.1 percent) than at Olmsted (Tables 25 and 26). *Quadrula pustulosa* (8.4 percent) and *Obliquaria reflexa* (8.0 percent), although moderately abundant at Post Creek, were much less abundant than *F. ebena*. A total of 16 species were represented among 286 individuals collected at all three quantitative sites. Other species obtained, and their percent abundance, were *Ellipsaria lineolata* (3.9), *Q. metanevra* (2.1), *Elliptio crassidens* (1.4), *Truncilla donaciformis* (1.4), *Q. quadrula* (1.4), *Amblema plicata* (1.4), *Obovaria olivaria* (1.4), *T. truncata* (1.4), *Q. nodulata* (1.1), *Megalonaias nervosa* (0.7), *Potamilus alatus* (0.7), *Tritigonia verrucosa* (0.35), and *Ligumia recta* (0.35). Species diversity was moderate (1.4 Shannon-Weaver; 0.95 Menhinick). Evenness of species relative abundance was moderate (0.39). Over half of all species showed at least some evidence of recent recruitment, meaning at least one individual less than 30 mm long was obtained. Approximately 14 percent of all individuals, regardless of species, were less than 30 mm long.

Four Mile Creek. Qualitative searches conducted at Four Mile Creek in September (3708.112 N, 8840.663 W; depth = 8 ft) yielded 238 individuals and 15 species, including many much larger and older specimens of several species (including *Fusconaia ebena*, *Amblema plicata*, *Quadrula pustulosa*, and *Megalonaias nervosa*) that are usually present at the Olmsted location. Dominance was shared by *Quadrula pustulosa* (n = 52) and *Fusconaia ebena* (n = 47). Also abundant were *Q. quadrula* (n = 34) and *Amblema plicata* (n = 27). Other species collected were *E. lineolata* (n = 16), *O. reflexa* (n = 12), *Q. metanevra* (n = 11), *M. nervosa* (n = 11), *P. alatus* (n = 10), *T. truncata* (n = 6), *Q. nodulata* (n = 5), *C. tuberculata* (n = 3), *T. verrucosa* (n = 2), *O. olivaria* (n = 1), and *E. crassidens* (n = 1).

Sediment adhered to the mussel shells was anoxic, with a strong hydrogen sulfide odor, unlike at Olmsted and Post Creek.

Size demography of native mussels. Quantitative samples taken at Olmsted in August 1997 indicated four substantially abundant cohorts in the dominant *F. ebena* population (Figure 42). Mussels of this population ranged in length from 8 to 78 mm. The most abundant cohort, with average length of approximately 40 mm, was the 1990 year class. The moderately small size of individuals in this cohort is due to depressed growth associated with heavy zebra mussel infestation that characterized most of the population in 1993. The cohort of large mussels centered at 71 mm represents surviving individuals of the 1981 cohort. Possibly two cohorts of very recent recruits were evident. One centered at 16 mm is likely to represent 1995 recruitment. A second centered at 10 mm probably represents 1996 recruitment.

Overall, the *F. ebena* population at Post Creek was similar (Figure 43), although the 1996 cohort was less clearly evident. It is noteworthy that

Table 25
Percent Abundance of Freshwater Mussels Collected from the Post Creek Site, Lower Ohio River, August 1997

Species	Subsite 1	Subsite 2	Subsite 3	Total
F. ebena	70.00	66.91	62.22	66.08
Q. pustulosa	3.33	9.56	10.00	8.39
O. reflexa	8.33	5.88	11.11	8.04
E. lineolata	5.00	3.68	3.33	3.85
Q. metanevra	1.67	2.94	1.11	2.10
E. crassidens	0.00	2.21	1.11	1.40
T. donaciformis	1.67	2.21	0.00	1.40
Q. quadrula	1.67	1.47	1.11	1.40
A. p. plicata	0.00	0.74	3.33	1.40
O. olivaria	5.00	0.74	0.00	1.40
T. truncata	0.00	1.47	2.22	1.40
Q. nodulata	1.67	0.00	2.22	1.05
M. nervosa	0.00	0.74	1.11	0.70
P. alatus	1.67	0.74	0.00	0.70
T. verrucosa	0.00	0.00	1.11	0.35
L. recta	0.00	0.74	0.00	0.35
Total individuals	60	136	90	286
Total species	10	14	12	16
Menhinick's index	1.29	1.20	1.26	0.95
Species diversity	1.21	1.36	1.41	1.40
Evenness	0.43	0.41	0.47	0.39
% Individuals <30 mm	13.29	15.67	7.69	13.87
% Species <30 mm	53.85	40	33.33	53.33

Table 26
Percent Occurrence of Freshwater Mussels Collected from the Post Creek Site, Lower Ohio River, August 1997

Species	Subsite 1	Subsite 2	Subsite 4	Total
F. ebena	90.0	100.0	100.0	96.7
Q. pustulosa	20.0	80.0	60.0	53.3
O. reflexa	40.0	50.0	60.0	50.0
E. lineolata	30.0	40.0	30.0	33.3
Q. metanevra	10.0	40.0	10.0	20.0
E. crassidens	0.0	30.0	10.0	13.3
T. donaciformis	10.0	20.0	0.0	10.0
Q. quadrula	10.0	20.0	10.0	13.3
A. p. plicata	0.0	10.0	30.0	13.3
O. olivaria	30.0	10.0	0.0	13.3
T. truncata	0.0	20.0	20.0	13.3
Q. nodulata	10.0	0.0	20.0	10.0
M. nervosa	0.0	10.0	10.0	6.7
P. alatus	10.0	10.0	0.0	6.7
T. verrucosa	0.0	0.0	10.0	3.3
L. recta	0.0	10.0	0.0	3.3
Total sites	10	10	10	30

the average length of the dominant 1990 cohort at Post Creek was approximately 44 mm—approximately 4 mm longer than at Olmsted. Previously, the studies have indicated that growth of this cohort at Olmsted was slowed during 2 years of heavy zebra mussel infestation. Generally lower infestation levels at Post Creek may account for the slightly greater length of the 1990 year class at that location. The average length of the 1981 cohort at Post Creek was 74 mm—again slightly larger than the same cohort at Olmsted. The 1995 cohort was approximately the same size at both Olmsted and Post Creek. This cohort was recruited after the extremely high densities of zebra mussels at Olmsted had declined.

Owing to the heavy abundance of *F. ebena*, few other species were collected in sufficient numbers to warrant detailed demographic analysis. However, *Q. p. pustulosa* populations at both Olmsted (Figure 44) and Post Creek (Figure 45) were clearly similar in the general size structure.

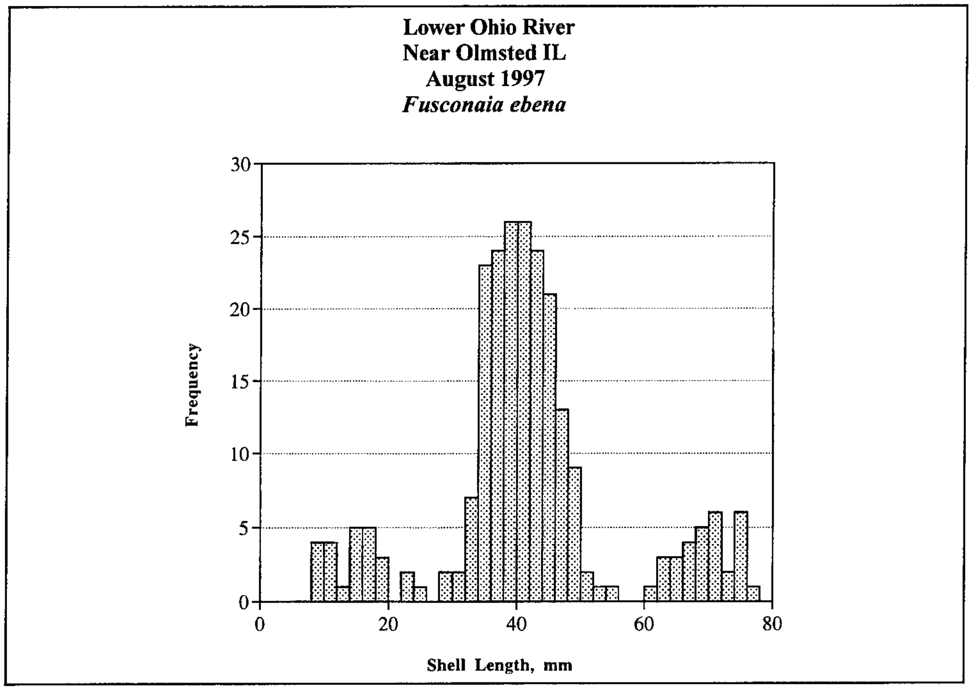


Figure 42. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River, August 1997

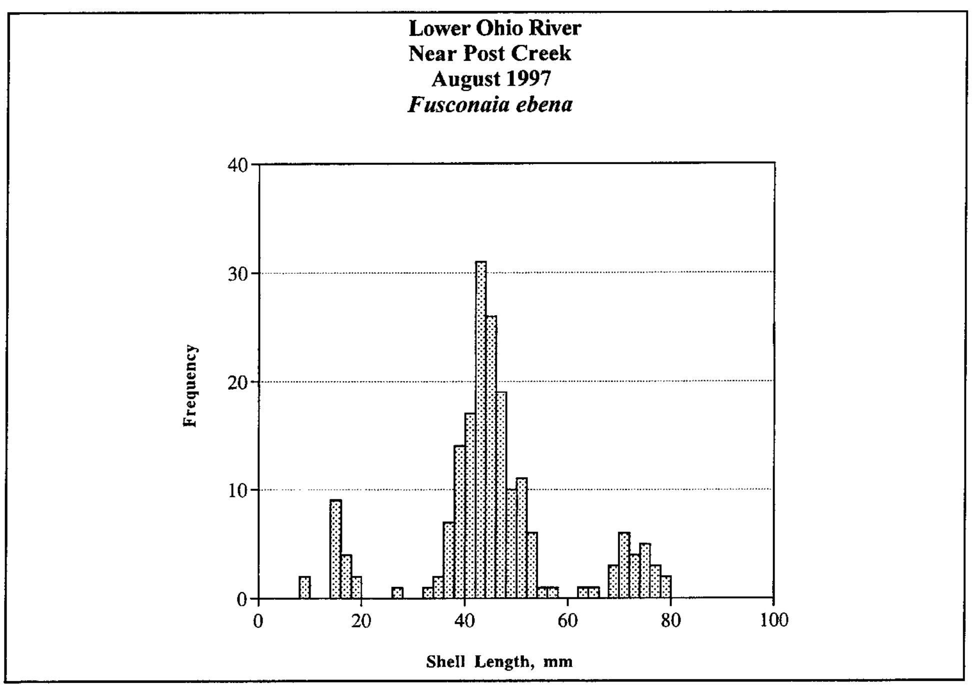


Figure 43. Length frequency histogram for *Fusconaia ebena*, Lower Ohio River near Post Creek, August 1997

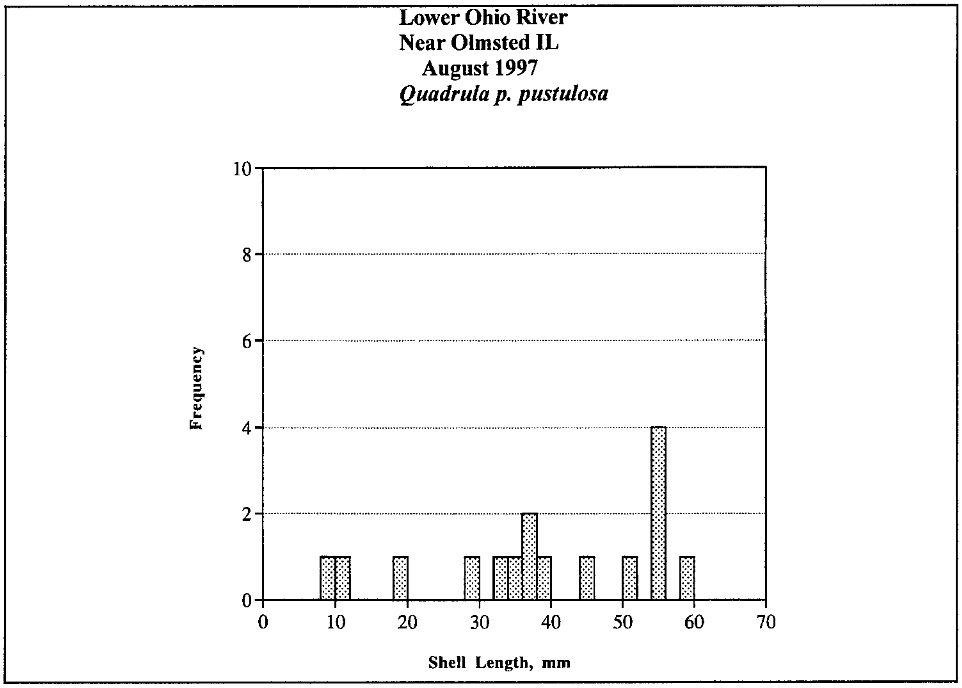


Figure 44. Length frequency histogram for *Quadrula p. pustulosa*, Lower Ohio River, August 1997

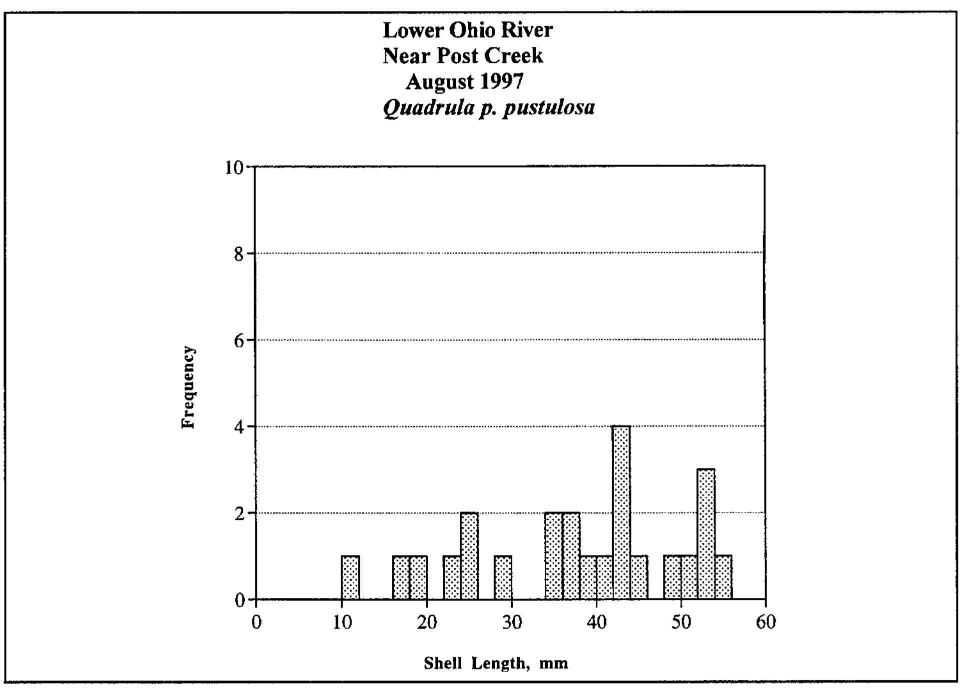


Figure 45. Length frequency histogram for *Quadrula p. pustulosa*, Lower Ohio River near Post Creek, August 1997

Both populations were comprised of approximately one-third recent recruits (<30 mm) and approximately two-thirds of mussels >30 mm. *Ellipsaria lineolata* populations at both sites included recent recruits (Figures 46 and 47). Nearly half of the *Obliquaria reflexa* at Post Creek was less than 30 mm long (Figure 48).

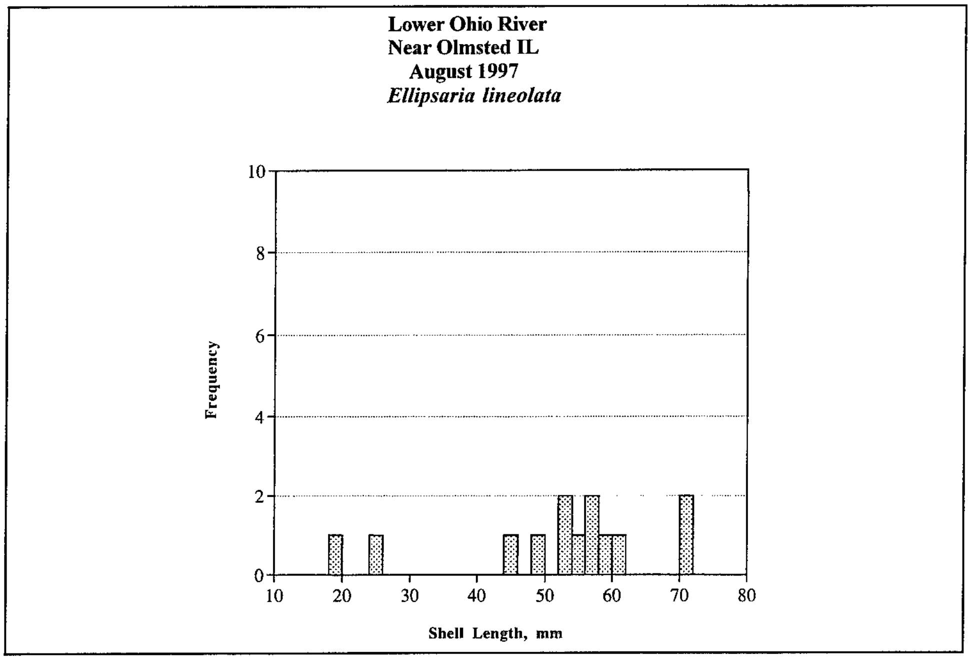


Figure 46. Length frequency histogram for *Ellipsaria lineolata*, Lower Ohio River, August 1997

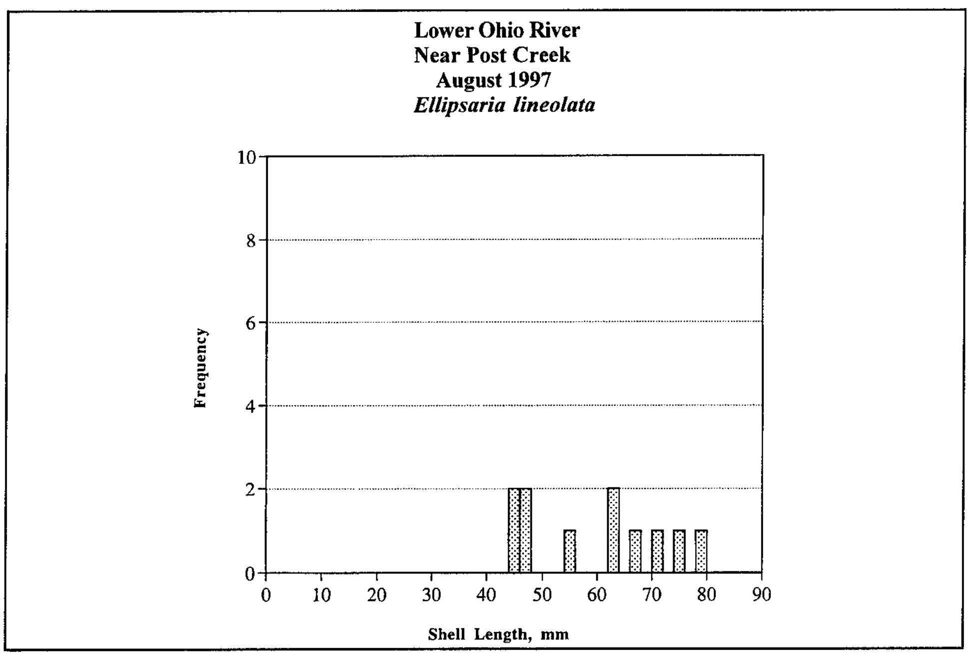


Figure 47. Length frequency histogram for *Ellipsaria lineolata*, Lower Ohio River near Post Creek, August 1997

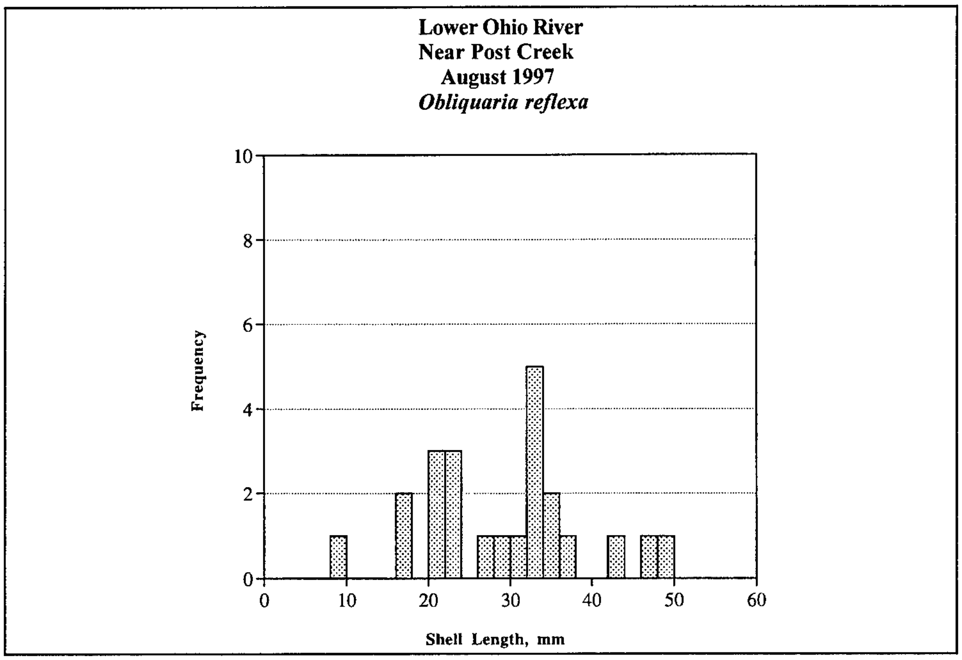


Figure 48. Length frequency histogram for *Obliquaria reflexa*, Lower Ohio River, August 1997

Nonindigenous species. Density of both *Dreissena polymorpha* and *C. fluminea* was low in August 1997, both at Olmsted and at Post Creek (Table 22). At Olmsted, density of *D. polymorpha* averaged just 195 individuals per square meter; density of *C. fluminea* was only 1.2 individuals per square meter. At Post Creek, density of these two species averaged only 113 and 3.9 individuals per square meter.

The size structure of the *Dreissena polymorpha* population at Olmsted is shown in Figure 49. The population consisted of essentially a single cohort. Individuals of this cohort ranged from 14 to 22 mm long. Average length was 18 mm. This cohort probably represents 1996 recruitment, and there was no evidence of a 1997 year class.

In slight contrast, the *D. polymorpha* population at Post Creek was dominated by similar size 1996 recruits, but there was some evidence of 1997 recruitment, as approximately 10 individuals less than 2 mm long were included in quantitative samples of zebra mussels (Figure 50). It was apparent that August sampling was slightly too early in the season to fully detect 1997 recruitment of zebra mussels.

The size structure of the *Corbicula fluminea* population was simple in August 1997, with only relatively small individuals present. Figure 51 summarizes this population at Post Creek. Essentially, a single cohort comprised the entire population. This cohort ranged from 6 to 16 mm long, with average length of 11 mm.

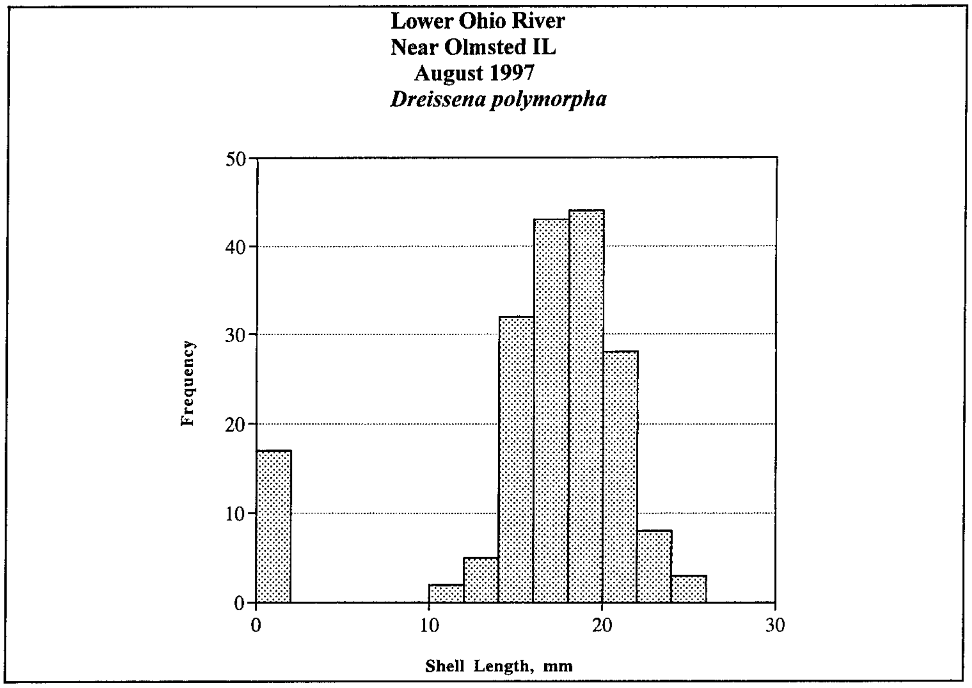


Figure 49. Length frequency histogram for the zebra mussel, *Dreissena polymorpha*, Lower Ohio River, August 1997

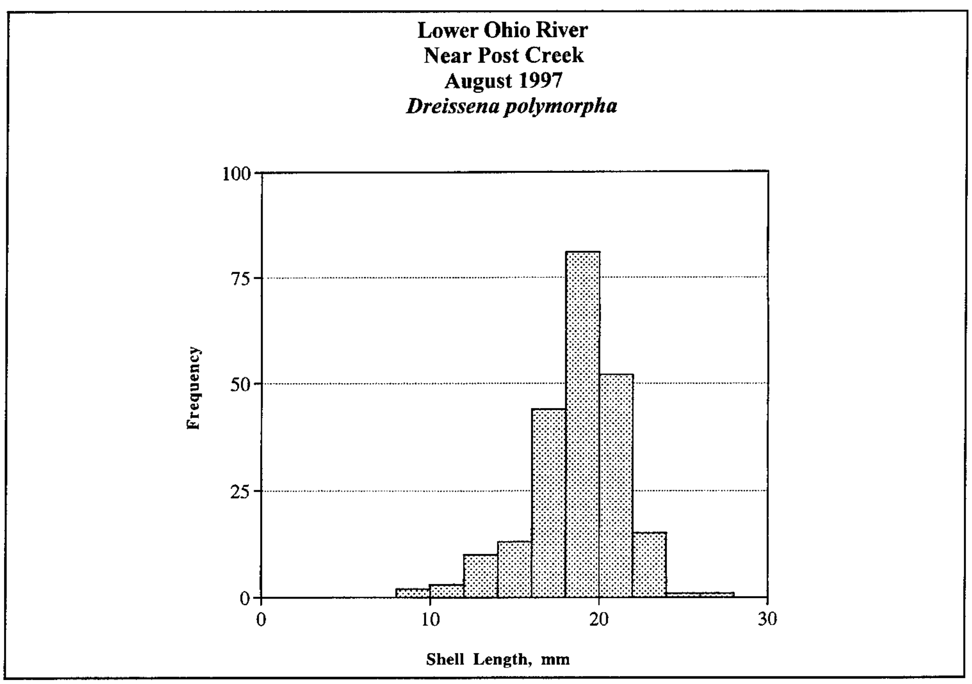


Figure 50. Length frequency histogram for the zebra mussel, *Dreissena polymorpha*, Lower Ohio River near Post Creek, August 1997

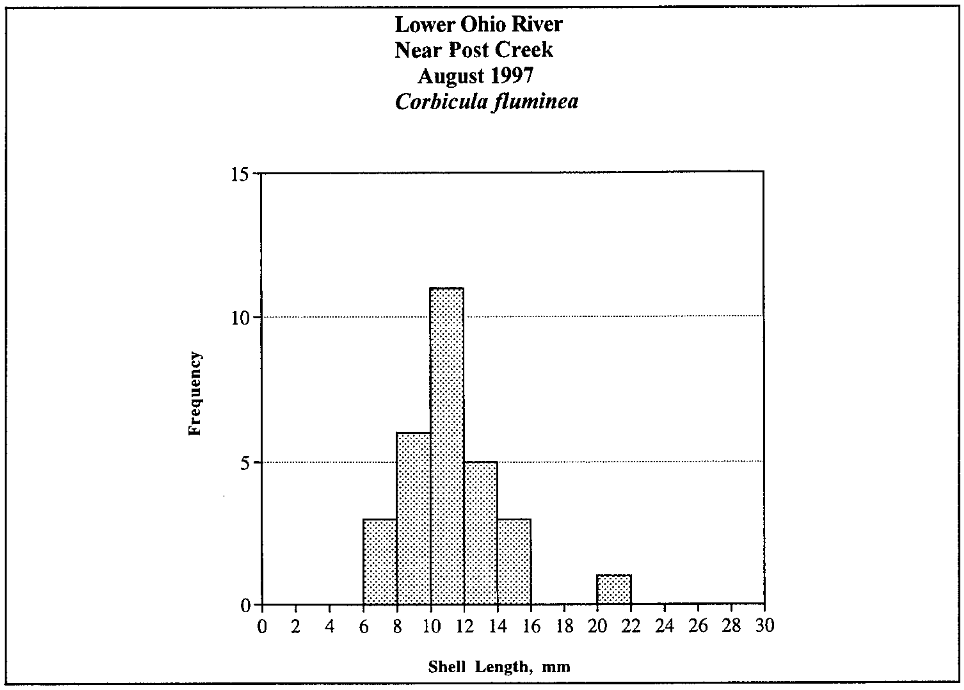


Figure 51. Length frequency histogram for *Corbicula fluminea*, Lower Ohio River, August 1997

The low densities of both *D. polymorpha* and *C. fluminea* are remarkable compared with recent abundances of these nonindigenous species in the lower Ohio River. *Dreissena* averaged more than 30,000 individuals per square meter as recently as 1994, reaching densities over 100,000 individuals per square meter at particular locations on the Olmsted shoal in 1994 (Payne and Miller 1997). Density of *Corbicula* routinely was measured at densities in excess of 1,000 individuals per square meter in the early to mid-1980s (Miller and Payne 1988). Furthermore, the *C. fluminea* population as recently as 1992 was characterized by multiple cohorts (3-5), with individuals 25-35 mm long being common. The very low density and simple age structure now characterizing *C. fluminea* fundamentally differs from the recent condition of this population in the lower Ohio River.

Pleurocerid snail abundance. Qualitative searches for pleurocerid snails were conducted to assess the recovery status of snail populations that were heavily decimated by high-density zebra mussel infestations from 1993 to 1995. The same sites used in qualitative sampling of native unionids in September at Olmsted were used for snail surveys. At the first site (278-ft elevation), 11 live snails were collected, by feel, during 20-min dives by each of two divers. At the second site (274-ft elevation) 7 live snails were obtained by two divers working 20 min each. Thus, although live pleurocerids were present on the shoal, their average density was extremely low (estimated between 0.1 and 1.0 per square meter). Species represented in these small collections were *Pleurocera canaliculatum* and *Lithasia verrucosa*.

5 Discussion

Spatial Characteristics of the Olmsted Mussel Bed

Studies in 1995 through 1997 confirmed earlier indications (Payne and Miller 1997) that the nearshore and farshore limits of the mussel bed correspond reasonably closely to the 279- and 267-ft elevation contours, respectively. As discussed by Payne and Miller (1997), the nearshore limit reflects historical patterns of extremely low river stage. During the winter of 1980/1981 and the summer and fall of 1988, the 279-ft elevation contour of the shoal was exposed to air for at least 14 consecutive days—enough to kill many unionids. The 281-ft elevation was exposed for maximum periods of 25, 35, and 59 consecutive days in the fall of 1976, winter of 1980/1981, and summer of 1988—enough to kill most unionids. Thus, it is not surprising that native mussel density is quite low nearshore of the 279-ft elevation contour. That *Dreissena polymorpha* density does not rapidly decline above this contour reflects the short life span of that species (<2 years) and, consequently, its ability to rapidly establish dense populations in areas that are only infrequently exposed to air. Long-lived native mussels require much longer durations of stable, suitable habitat conditions.

In the farshore direction, the boundary of the mussel bed is somewhat less distinct. Increasingly erosional conditions cause scoured sand and bedrock to be the predominant substratum farshore of elevation 267. However, isolated patches of somewhat more stable substratum (sand or sand and gravel) are occasionally encountered farshore of elevation 267 that support dense assemblages of mussels. In addition, patches of sand that may not be stable for more than a few years temporarily can provide suitable substratum for recent recruits. The lack of large, old mussels in such patches suggests that such substratum and mussels are eventually swept away by scouring flows, preventing the establishment of a complex age structure in mussel assemblages encountered much farshore of elevation 267.

Within the mussel bed, there is a high degree of variability in mussel density. In general, substratum type is not clearly correlated with mussel density between the 279 and 267 elevation contours, except that erosional patches of sand or bedrock obviously do not support mussels. Patchiness of mussel density is apparent among quadrats within sites as well as among sites. Both a high degree of sample replication (i.e., at least 10 quadrats per site) and some degree of site replication (at least two closely adjacent subsites per site) are required to establish if location-specific estimates of density are to be confidently compared to establish spatial patterns of density distribution.

Previously used categories of <20, 20-50, and >50 mussels per square meter to describe low-, moderate-, and high-density assemblages still seem reasonable in the face of data gathered from 1995 to 1997. Although densities of 200-300 individuals per square meter are occasionally encountered, these are outlier data and always are due to extremely dense clusters of recent recruits (especially *F. ebena*). A density range of 50 to 100 individuals per square meter is more likely to correspond to "local carrying capacity" with respect to a complex, age-structured assemblage.

Community Composition

Fusconaia ebena is clearly heavily dominant in the stable shoals of the lower Ohio River. This is true to the extent that even a relatively species rich community such as that at Olmsted is nonetheless correctly described as having low diversity. This of course is a direct consequence of the fact that high relative abundance of the dominant species mathematically forces a low value when computing a diversity index such as those of Shannon-Weaver or Menhinick. In a broad sense, where diversity equals richness, the lower Ohio River community is indeed diverse. Approximately 32 species of native unionids occur in the shoal at Olmsted (Payne and Miller 1997).

Fusconaia ebena was once the dominant unionid of stable shoals in the main channel of both the lower Ohio and upper Mississippi rivers. This species has high commercial value due to its large size, heavy shell, and white nacre. In the lower Ohio, *F. ebena* occurs with the Federally endangered species *Plethobasus cooperianus*. Like species of the genus *Plethobasus*, *F. ebena* thrives in gravelly shoals of large unimpounded rivers. Such habitat was central to the evolution of the rich North American unionid fauna. Thus, in several aspects, protection of *F. ebena* and its habitat equates with protection of unionid diversity in large rivers. Certainly this is true of the lower Ohio River, where *F. ebena* is truly a species of ecological, commercial, cultural, and legal significance.

Not only does *F. ebena* heavily dominant the lower Ohio River mussel community but a single-year class of this species typically dominates that population (and thus the community as well). From 1981 until 1990, an exceptionally successful 1981 cohort of *F. ebena* heavily dominated the native mussel community. In 1990, this cohort was replaced in its dominance by another very successful year class. In other years, such as 1995 and 1996, there is often some recruitment evident, but the extremely abundant cohorts overwhelm the age structure of the *F. ebena* population. As a practical matter, such dominant cohorts can be followed through time to establish, without relying on any manipulative studies (such as caging or mark and recapture) or subjective methods (annual shell rings) to provide growth and mortality estimates. That the 1981 cohort is still obvious in the population in 1997 indicates average longevity of at least 16 years. The length of an average individual of this cohort is still only 72-74 mm—well below the maximum length of approximately 90 mm that has been previously observed in this population. Thus, average longevity is likely to be considerably greater than 16 years. Continued monitoring can establish this longevity with a naturally occurring cohort.

It is especially noteworthy that *F. ebena* recruitment was evident for the 1995- and 1996-year classes. This recruitment has occurred since the establishment of the nonindigenous zebra mussel in this mussel bed.

Good recruitment appears to be a community-wide phenomenon; recent recruitment has not been restricted to *F. ebena*. One or a few individuals of less than 30-mm length have been recovered of nearly all species present on the bed. Obviously, the rarest species yield so few individuals that it is possible to miss recent recruits of those taxa even if they exist.

Resilience to Nonindigenous Species Invasion

Native mussels in the lower Ohio River, including *F. ebena*, have been resilient to high-density populations of nonindigenous bivalves. The first such species invasion was by the Asian clam, *C. fluminea*. A dense population of this species in the lower Ohio River was first observed in 1957 (Sinclair and Isom 1961; McMahon 1983). The sampling at Olmsted began in 1983. From 1983 to 1993, *C. fluminea* was very dense (typically 1,000 to 3,000 individuals per square meter) and populations were characterized by complex age and size structure (typically three to five cohorts) with the the oldest and largest individuals being 2 to 3 years old and 30 to 40 mm long. Despite sustained high density and complex demography of *C. fluminea*, no correlation was found between native mussel and *C. fluminea* density within the Olmsted bed (Miller and Payne 1988). A negative relationship would have been evidence of competition between these taxa. Since 1993, *C. fluminea* density has greatly declined, and the population now has simple age structure (typically one cohort) and includes few individuals greater than 15 mm long.

Dreissena polymorpha first appeared in the lower Ohio River in 1991 (Payne, Miller, and Shafer 1994) and has replaced *C. fluminea* as the dense nonindigenous bivalve existing with native mussels. However, only the 1994 generation of *D. polymorpha* has been extremely dense

(49,000 individuals per square meter in September 1994 to 5,000 individuals per square meter in July 1995; Figure 18). This dense cohort heavily infested native mussels in 1994 and early 1995, resulting in reduced unionid growth (Figures 5, 6, 16, and 17), but did not cause catasrophic declines in density such as have been reported in the Great Lakes (e.g., Nalepa 1997). High density of *D. polymorpha* has not been sustained in the lower Ohio River. Cohorts since the 1994 year class have not been especially dense. It remains to be seen if *D. polymorpha* can occur in sustained abundance in the lower Ohio River at a density sufficiently high to have drastic effects on native bivalves.

Future Considerations

Personnel of the U.S. Army Engineer Waterways Experiment Station have used qualitative and quantitative methods to collect bivalves in the lower Ohio River since 1983. Results indicate that mussel beds of the lower Ohio River remain characterized by high richness, heavy dominance of *F. ebena*, good recruitment rates of juveniles (albeit annually quite variable), and resilience to nonindigenous species invasions. This resilience may be a consequence of the inability, thus far, of zebra mussels to establish sustained high-density populations. However, the mussel bed clearly was resilient to long-term high density of *C. fluminea* (from approximately 1958 to the late 1980s). *Fusconaia ebena* was once the dominant thick-shelled unionid of stable river shoals throughout the lower Ohio River and the upper Mississippi River. In the lower Ohio River, its dominance has corresponded with other indicators of a healthy community, including high richness, resilience, recruitment, and presence of an endangered species. These traits all suggest that mussel beds of the lower Ohio River remain among the most ecologically valuable and interesting in the nation.

Continued monitoring using qualitative and quantitative methods will provide data that can be used to determine if construction and operation of the Olmsted Locks and Dam project has negative effects on the mussels of the lower Ohio River. Long-term data have proven invaluable for interpreting causes and significance of fluctuations in physical and biological parameters, including population and community demographics and abundance of nonindigenous species.

References

Aldridge, D. W., Payne, B. S., and Miller, A.C. (1987). "The effects of intermittent exposure to suspended solids and turbulence on three species of freshwater mussels," *Environmental Pollution* 45, 17-28.

Holland, L. E. (1986). "Effects of barge traffic on distribution and survival of ichtyoplankton and small fishes in the upper Mississippi River," *Transactions of the American Fisheries Society* 115, 162-165.

Killgore, K. J., Miller, A. C., and Conley, K. C. (1987). "Effects of turbulence on yolk-sac larvae of paddlefish," *Transactions of the American Fisheries Society* 116, 670-673.

McMahon, R. F. (1983). "Ecology of an invasive pest bivalve, *Corbicula fluminea*." *The Mollusca, Vol. 6, Ecology*. W. D. Russell-Hunter, ed., Academic Press, Inc., Orlando, FL, 505-561.

Miller, A. C., and Payne, B. S. (1988). "The need for quantitative sampling to characterize size demography and density of freshwater mussel communities," *Bulletin of the American Malacological Union, Inc.* 6, 49-54.

__________. (1991). "Co-occurrence of native freshwater mussels (unionidae) and the nonindigenous *Corbicula fluminea* at two stable shoals in the Ohio River, U.S.A.," *Malacological Review* 27, 87-97.

Miller, A. C., Payne, B. S., and Siemsen, T. (1986). "Description of the habitat of the endangered mussel *Plethobasus cooperianus*," *The Nautilus* 100, 14-18.

Nalepa, T. (1994). "Decline of native unionid bivalves in Lake St. Clair after infestation by the zebra mussel, *Dreissena polymorpha*," *Can. J. Fish. Aquat. Sci.* 51, 2227-2233.

Neff, S. E., Pearson, W. D., and Holdren, G. C. (1981). "Aquatic and terrestrial communities in the lower Ohio River (RM 930-981)," Contract Report submitted to the U.S. Army Engineer District, Louisville, Louisville, KY.

Payne, B. S., Killgore, K. J., and Miller, A. C. (1990). "Mortality of yolk-sac larvae of paddlefish, *Polydon spathula*, entrained in high-velocity water currents," *Journal of Mississippi Academy of Sciences* 35, 7-9.

Payne, B. S., and Miller, A. C. (1987). "Effects of current velocity on the freshwater bivalve *Fusconaia ebena*," *Bulletin of the American Malacological Union, Inc.* 5, 177-179.

__________. (1989). "Growth and survival of recent recruits to a population of *Fusconaia ebena* (Bivalvia: Unionidae) in the lower Ohio River," *American Midland Naturalist* 121, 99-104.

__________. (1997). "Spatial distribution of mussels at a bed in the lower Ohio River near Olmsted, Illinois," Technical Report EL-97-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Payne, B. S., Miller, A. C., and Aldridge, D. W. (1987). "Environmental effects of navigation traffic: Laboratory studies of the effects on mussels of intermittent exposure to turbulence and suspended solids," Technical Report EL-87-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Payne, B. S., Miller, A. C., and Shafer, D. (1994). "An analysis of freshwater mussels (Unionidae) in the lower Ohio River at two beds near Olmsted, Illinois: 1992 studies," Technical Report EL-94-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Ricciardi, A., Whoriskey, F. G., and Rasmussen, J. B. (1995). "Predicting the intensity and impact of *Dreissena* infestation native unionid bivalves from *Dreissena* density," *Can. J. Fish. Aquat. Sci.* 52, 1449-1461.

Schloesser, D. W., and Nalepa, T. F. (1994). "Dramatic decline of native unionid bivalves in offshore waters of western Lake Erie after infestation by the zebra mussel, *Dreissena polymorpha*," *Can. J. Fish. Aquat. Sci.* 51, 2234-2242.

Sinclair, R. M., and Isom, B. G. (1961). "A preliminary report on the introduced Asiatic clam *Corbicula* in Tennessee," Tennessee Stream Pollution Control Board, Tennessee Department of Public Health, Nashville, TN.

Taylor, R. W. (1989). "Changes in freshwater mussel populations of the Ohio River: 1,000BP to recent times," *Ohio Journal of Science* 89, 188-191.

U.S. Army Corps of Engineers. (1991). Draft Supplement I, Final Environmental Impact Statement for the Replacement of Locks and Dams 52 and 53 (Olmsted Locks and Dams), Lower Ohio River, IL-KY, U.S. Army Engineer District, Louisville, Louisville, KY.

U.S. Fish and Wildlife Service. (1991). "Endangered and threatened wildlife and plants," *Federal Register*, July 15, 1991, 50 CFR 17.11 and 17.12.

Williams, J. C. (1969). "Mussel fishery investigations, Tennessee, Ohio and Green rivers," Project Completion Report for Investigations Projects Under the Commercial Fisheries Research and Development Act of 1964, U.S. Fish and Wildlife Service and Kentucky Department of Fish and Wildlife Resources.

Williams, J. C., and Schuster, G. A. (1982). "Freshwater mussel investigations in the Ohio River Mile 317.0 to Mile 981.0," A report submitted to the Department of Fish and Wildlife Resources, Division of Fisheries, Frankfort, KY.

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13. ABSTRACT ***(Maximum 200 words)***

Surveys were conducted in 1995, 1996, and 1997 to assess community characteristics, population demography of dominant species, status of endangered species, and characteristics of nonindigenous populations of freshwater bivalves in the lower Ohio River. Data will be used to analyze impacts of construction and operation of a new lock and dam at River Mile (RM) 964.4. The greatest focus has been on a mussel bed just downstream of the project. Density categories of <20, 20 to 50, and >50 individuals per square meter are reasonable for delineating low-, moderate-, and high-density assemblages within this bed. Density >200 individuals per square meter is occasionally measured, but always describes a location heavily dominated by recent recruits.

The native mussel community of the lower Ohio River is dominated by *Fusconaia ebena*. Dominance of this species was high at RM 967 (near Olmsted, IL), typically exceeding 80 percent of the community. At RM 957 (near Post Creek, IL), *F. ebena* is much less dominant (33 percent). Species richness is similar at both locations. The *F. ebena* population in the lower Ohio River is heavily dominated by a single-year class (probably 1990) of recent recruits. Prior to the exceptional recruitment in 1990, this population was dominated by a very abundant 1981 cohort.

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The nonindigenous zebra mussel, *Dreissena polymorpha*, attained very high density (10,000 to 100,000 individuals per square meter) in 1993 through 1994. Since 1994, zebra mussel density has not exceeded 10,000 individuals per square meter. The 1990 cohort of *F. ebena* has grown more slowly than was predicted by the early growth of the 1981 cohort, apparently because of recent and exceptionally high infestation by zebra mussels. Mortality due to zebra mussel infestation has not decimated the native mussels of the lower Ohio River. The native mussel community remains dense and diverse, and live specimens of the endangered species *Plethobasus cooperianus* can still be obtained. These mussel beds in the lower Ohio River remain characterized by high density, richness (including endangered species), strong recruitment, and resilience to nonindigenous species.